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ENVIRONMENTAL ENDURANCE TESTING OF AN ELASTOMERIC PITCH CHANGE BEARING

David L. Myers

Lord Kinematics

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ENVIRONMENTAL ENDURANCE TESTING OF AN ELASTOMERIC PITCH CHANGE BEARING

By

David L. Myers

February 1973

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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LORD KINEMATICS
A DIVISION OF LORD CORPORATION
ERIE, PENNSYLVANIA

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13. ABSTRACT

Presented in this report are the results of pre-endurance and environmental endurance testing of the LM-726-1 elastomeric pitch change bearing designed for the all-elastomeric rotor in the AH-1G helicopter. Testing was conducted to form a basis for determining the airworthiness of the bearing in terms of expected reliability and inspection and replacement criteria.

Pre-endurance testing was intended to establish the bearings' performance characteristics and suitability for environmental endurance testing. Torsional, axial, and radial load-deflection curves are presented. The results of an axial repeated load test are discussed, and data from a limited experimental stress analysis is presented. Pre-endurance testing showed the LM-726-1 bearing to be suitable for environmental endurance testing.

Environmental endurance testing was conducted on six LM-726-1 bearings in a specially designed fatigue test machine. Three pairs of samples were subjected to the loads and motions expected in service as determined by the AH-1G flight test program conducted on a conventional rotor and on a prototype all-elastomeric rotor. Two of the three bearing pairs were exposed to environments typical of helicopter service conditions. The remaining set was exposed to the load/motion spectrum under room temperature laboratory conditions to provide a basis for comparison. Periodic inspections of the bearings' performance characteristics were conducted as a monitor of their condition.

The environmental endurance test procedure is briefly discussed, and results are presented in detail. All of the samples were tested to failure, and the modes of failure are discussed. A reliability analysis indicating a B-10 life of 812 hours using the Weibull analysis technique is presented. Recommendations are made for inspection and replacement of elastomeric bearings based on the tests conducted. The testing has shown the need for additional efforts toward qualifying the LM-726 type bearing, and recommendations for these efforts are presented.

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DEPARTMENT OF THE ARMY
U. S. ARMY AIR MOBILITY RESEARCH & DEVELOPMENT LABORATORY
EUSTIS DIRECTORATE
FORT EUSTIS, VIRGINIA 23604

This report was prepared by Lord Kinematics, a Division of Lord Corporation, under the terms of Contract DAAJ02-71-C-0044. It documents the results of an environmental/endurance test program designed to determine the expected reliability of the Lord LM 726-1 Elastomeric Pitch Change Bearing under loads and motions derived from flight data of the Bell Helicopter Company Model 540 Rotor System. It defines failure modes and phenomena and offers inspection and replacement criteria.

The feasibility of the LM 726-1 elastomeric bearing was previously demonstrated in a limited flight test program. The 9 hours of flight testing confirmed that steady and oscillatory loads for the hub, blade, and controls were comparable to baseline data for the conventional main rotor. The objective of the environmental/endurance program was to ensure that the LM 726-1 offered a significantly higher service life than the present hardware and also exhibited desirable reliability and maintainability features.

The conclusions contained herein are concurred in by this Directorate; however, it should be noted that the 812-hour Weibull Analysis B-10 life of the bearings is a value indicative of the bench test life. Another elastomeric bearing configuration having a similar bench life has far exceeded that life in flight tests.

The technical monitor for this contract was Mr. John W. Sobczak of the Military Operations Technology Division.

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February 1973

ENVIRONMENTAL ENDURANCE TESTING OF AN ELASTOMERIC PITCH CHANGE BEARING

Final Report

Lord Engineering Report PE-158

By

David L. Myers

Prepared by

Lord Kinematics
A Division of Lord Corporation
Erie, Pennsylvania

for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

SUMMARY

Presented in this report are the results of pre-endurance and environmental endurance testing of the LM-726-1 elastomeric pitch change bearing designed for the all-elastomeric rotor in the AH-1G helicopter. Testing was conducted to form a basis for determining the airworthiness of the bearing in terms of expected reliability and inspection and replacement criteria.

Pre-endurance testing was intended to establish the bearings' performance characteristics and suitability for environmental endurance testing. Torsional, axial, and radial load-deflection curves are presented. The results of an axial repeated load test are discussed, and data from a limited experimental stress analysis is presented. Pre-endurance testing showed the LM-726-1 bearing to be suitable for environmental endurance testing.

Environmental endurance testing was conducted on six LM-726-1 bearings in a specially designed fatigue test machine. Three pairs of samples were subjected to the loads and motions expected in service as determined by the AH-1G flight test program conducted on a conventional rotor and on a prototype all-elastomeric rotor. Two of the three bearing pairs were exposed to environments typical of helicopter service conditions. The remaining set was exposed to the load/motion spectrum under room temperature laboratory conditions to provide a basis for comparison. Periodic inspections of the bearings' performance characteristics were conducted as a monitor of their condition.

The environmental endurance test procedure is briefly discussed, and results are presented in detail. All of the samples were tested to failure, and the modes of failure are discussed. A reliability analysis indicating a B-10 life of 812 hours using the Weibull analysis technique is presented. Recommendations are made for inspection and replacement of elastomeric bearings based on the tests conducted. The testing has shown the need for additional efforts toward qualifying the LM-726 type bearing, and recommendations for these efforts are presented.

FOREWORD

This report contains the results of testing performed by Lord Kinematics under Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory (USAAMRDL) Contract DAAJ02-71-C-0044 (Task 1F163204DB38).

The contracted work was conducted under the technical cognizance of Mr. John Sobczak of the Eustis Directorate, USAAMRDL. Principal Lord personnel involved in the program were Messrs. J. Gorndt, J. Grantham, D. Myers, and J. Potter. In addition, technical assistance was received from Messrs. W. Cresap and C. Fagan of Bell Helicopter Company.

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INTRODUCTION

Elastomeric bearings employ a "high capacity" concept which allows accommodation of oscillatory motions through shear of the elastomer while carrying relatively high steady and oscillatory loads through compression of the elastomer. Alternate layers of elastomer and metal shims which are thin in relation to the overall stack height of the flexing element are designed to accommodate different combinations of loads and motions. Proper selection of elastomer layer thickness and geometries will result in a part which is capable of replacing conventional rolling element bearings in a number of applications. The majority of these applications to date have been in helicopter rotor systems.

Elastomeric bearings offer a number of advantages when compared to conventional bearings. The need for lubrication is eliminated, and rotor system maintenance is greatly reduced. Flight evaluations of elastomeric bearings conducted to date have resulted in bearing fatigue lives well in excess of that previously achieved with other types of bearings. Greater reliability will greatly curtail unscheduled maintenance by reducing the number of premature bearing failures.

The LM-726-1 bearing is a conical configuration specifically designed to carry the blade centrifugal force load along the cone axis and radial loads resulting from blade moments perpendicular to the cone axis. Pitch change motion, steady and oscillatory, is accommodated through torsional shear of the elastomer about the cone axis. The LM-726-1 was specifically designed for the load, motion, and life requirements of the Bell Helicopter Model 540 Rotor System.

A limited laboratory and flight test evaluation jointly conducted in late 1970 and early 1971 by Bell Helicopter Company and Lord Manufacturing Company, under USAAVLABS sponsorship, demonstrated the feasibility of the LM-726-1 bearing for use in the above-mentioned rotor system. The results of this testing are contained in USAAVLABS Technical Report 71-16.*

*Fagan, C. H., FLIGHT EVALUATION OF ELASTOMERIC BEARINGS IN AN AH-1 HELICOPTER MAIN ROTOR, USAAVLABS Technical Report 71-16, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, March 1971, AD 725595.

Additional laboratory fatigue testing of the LM-726-1 was recommended as the fastest and least expensive means of determining its expected service life. Loads and motions were selected based on in-flight measurements on the standard and on the prototype Model 540 All-Elastomeric Rotor System. Environmental conditions typical of those expected in service were selected and imposed on the bearings simultaneous with the fatigue conditions. This test was intended to establish bearing life as well as to generate inspection and replacement guidelines.

The endurance test followed preliminary pre-endurance testing and intended to establish bearing performance characteristics and to verify the bearings' suitability for continued testing. An axial fatigue test was included as a portion of the pre-endurance test in order to evaluate a new outer housing design incorporated as a result of previously conducted tests.

TEST SAMPLES

Fifteen LM-726-1 bearings were manufactured and allocated as shown in Table I. After serialization, static torsional and axial load-deflection tests were performed on each sample individually. The results are summarized in Table II. The nominal axial deflection at 56,000 lb axial load was .100 inch with a total variation of $\pm$ .003 or 3%. The nominal torque required to achieve a 15-degree windup was 2150 in.-lb, with a variation of $\pm$ 100 in.-lb or 4.6%. A greater variation in spring rate characteristics could be expected from two separate lots of bearings. All samples were inspected for compliance with Lord drawing LM-726-1, Rev. H., prior to any testing. This drawing is contained in Test Plan 8B035 of the appendix.

TABLE I. DISPOSITION OF TEST SAMPLES

Bearing Serial Number	Test Sample Number	Disposition of Bearing
001	1	Endurance Test Bearing
002	2	Endurance Test Bearing
004	3	Endurance Test Bearing
005	4	Endurance Test Bearing
006	5	Endurance Test Bearing
007	6	Endurance Test Bearing
003	7	Pre-Endurance Test Bearing
008	8	Pre-Endurance Test Bearing
014	9	Pre-Endurance Test Bearing
009	10	Deliver to Government
010	11	Deliver to Government
011	12	Deliver to Government
012	13	Deliver to Government
013	14	Spare Bearing
015	15	Spare Bearing

TABLE II. STATIC AXIAL AND TORSIONAL SPRING RATES

Bearing Serial Number	Test Sample Number	Axial Def. at 56K CF (in.)	Axial Spring Rate (lb/in.)	Torque at 15° Tors. Windup (in.-lb)	Torsional Spring Rate (in.-lb/deg)
001	1	.099	565,000	2250	150
002	2	.098	571,000	2200	147
004	3	.103	543,000	2125	142
005	4	.102	549,000	2175	145
006	5	.102	549,000	2150	143
007	6	.101	554,000	2175	145
003	7	.099	565,000	2050	137
008	8	.098	571,000	2100	140
014	9	.101	554,000	2175	145
009	10	.097	577,000	2175	145
010	11	.098	571,000	2200	147
011	12	.100	560,000	2175	145
012	13	.099	565,000	2200	147
013	14	.103	543,000	2150	143
015	15	.101	554,000	2150	143

PRE-ENDURANCE TESTING

INTRODUCTION

Pre-endurance testing was conducted to verify the LM-726-1 bearings' predicted performance and suitability for environmental endurance testing and to evaluate the strength of the metal components. The stiffness of the outer housing was of particular interest. It had been redesigned to reduce ovalling observed in previous tests during the application of the centrifugal force. The ovalling results from the stiffness added to the outer housing by the lug attachment provisions. Improved fatigue life resulting from a more even distribution of the compression stress on the elastomer was the goal of the housing modification.

PRE-ENDURANCE SPRING RATE TESTS

Individual axial and torsional load-deflection tests on test samples 7, 8, and 9 were performed. Table II contains the secant axial and torsional spring rates. Figures 1 and 2 are the load-deflection curves of test sample 7 in the axial and torsional directions, respectively. These curves are typical of all fifteen test samples. Figures 3 and 4 illustrate the individual axial and torsional load-deflection fixtures. Test samples 7 and 8 were installed in the radial load-deflection fixture and loaded in parallel with the normal centrifugal force of 56,000 pounds applied. Tests were performed in the blade chordwise and beamwise directions with the results contained in Figure 5 . Figure 6 illustrates the test sample pair installed in the test fixture prior to the chordwise radial load-deflection test. The test fixture is shown installed in the universal test machine in Figure 7.

The test frame containing test samples 7 and 8 was installed in a torsional test machine with links attached to the center block for applying pitch motion. The test fixture is shown in Figure 8 . Torsional load-deflection tests on the bearing pair with centrifugal forces of 0, 56,000 pounds, and 84,000 pounds were performed, and the results shown in Figures 9, 10, and 11.

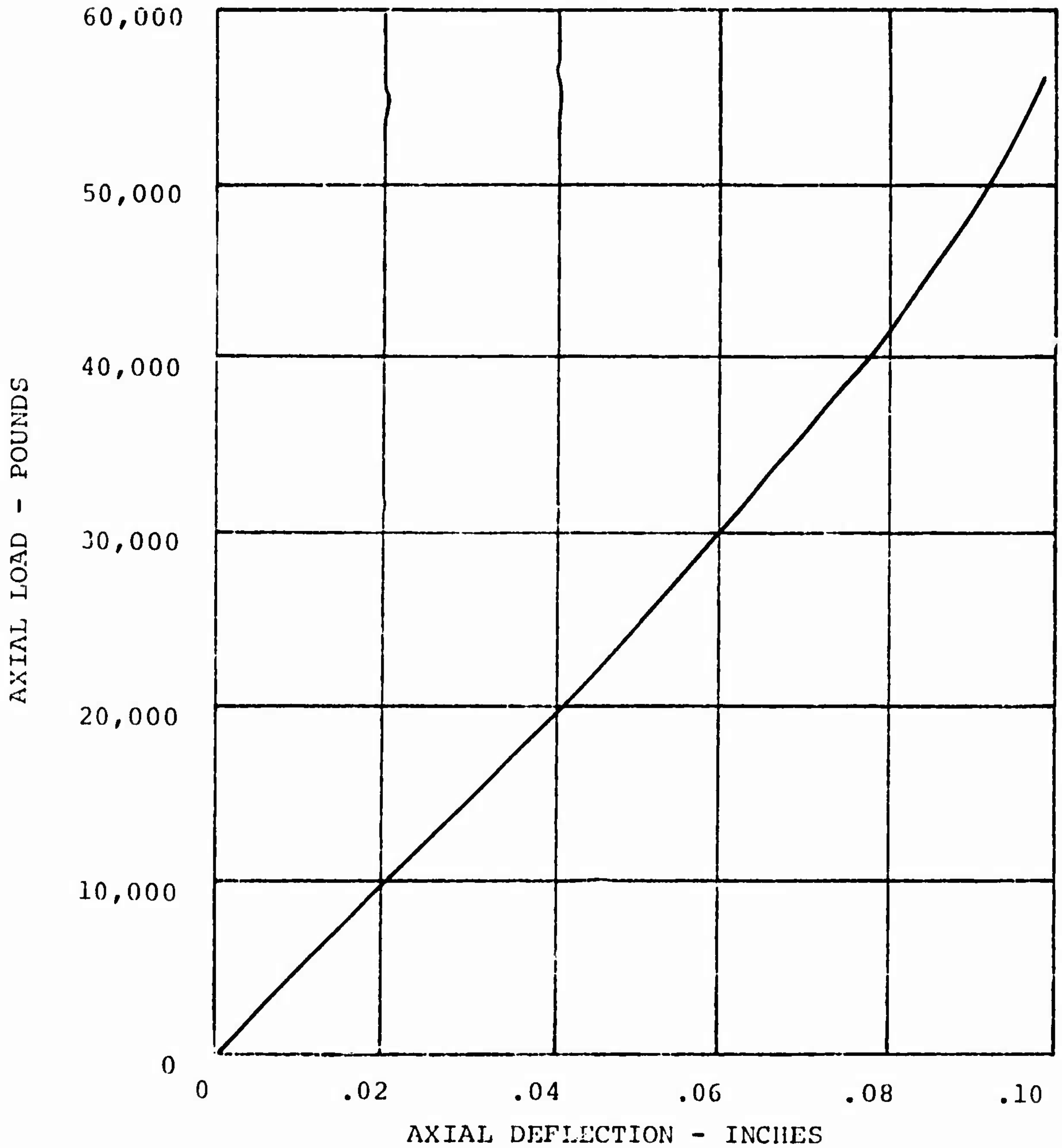


Figure 1. Axial Spring Rate of LM-726-1, S/N 003, Test Sample 7.

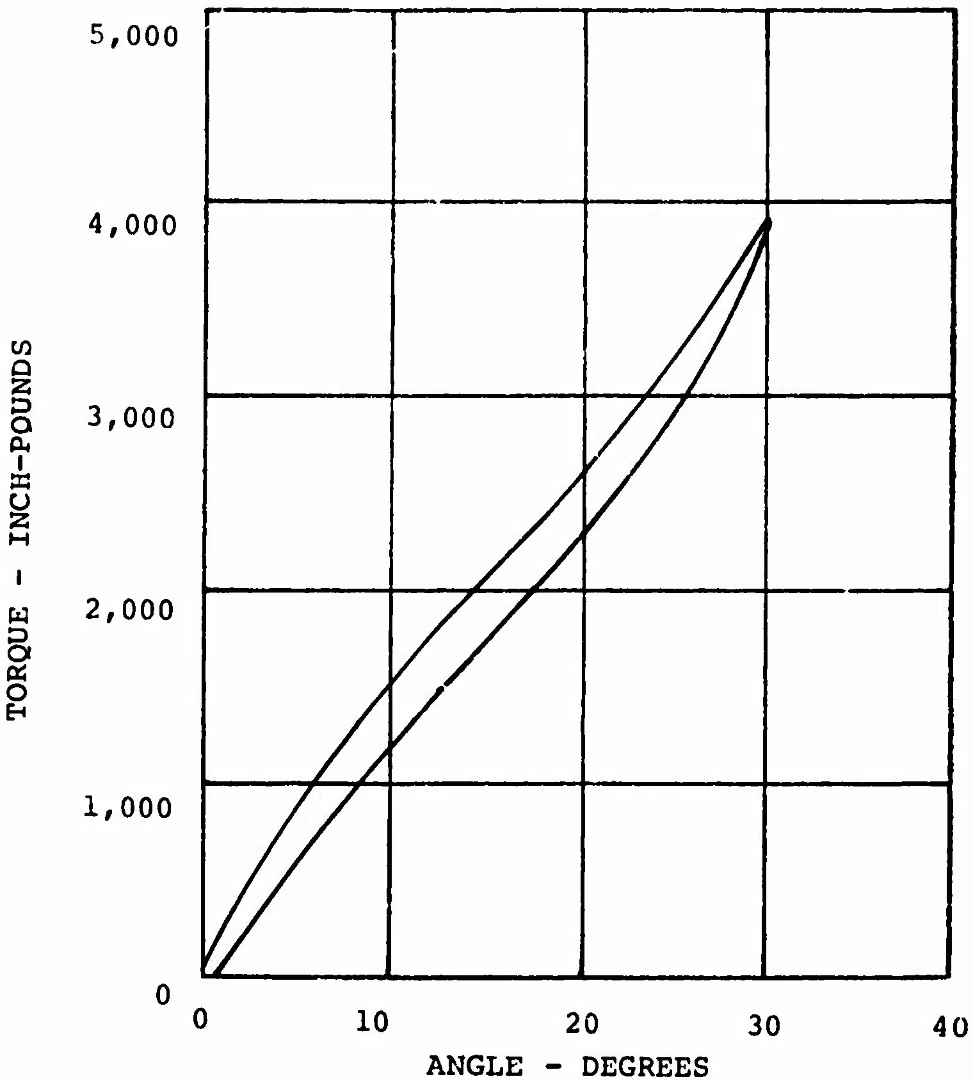


Figure 2. Torsional Spring Rate of LM-726-1, S/N 003, Test Sample 7.

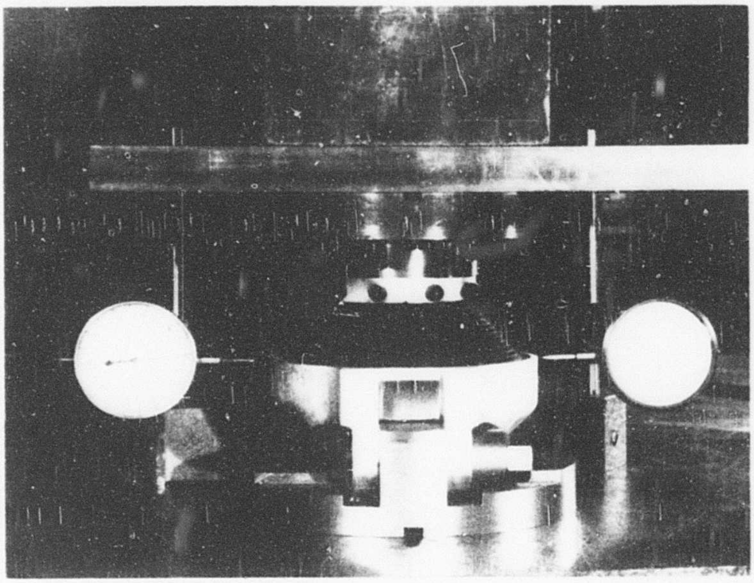


Figure 3. Static Axial Load Deflection Fixture.

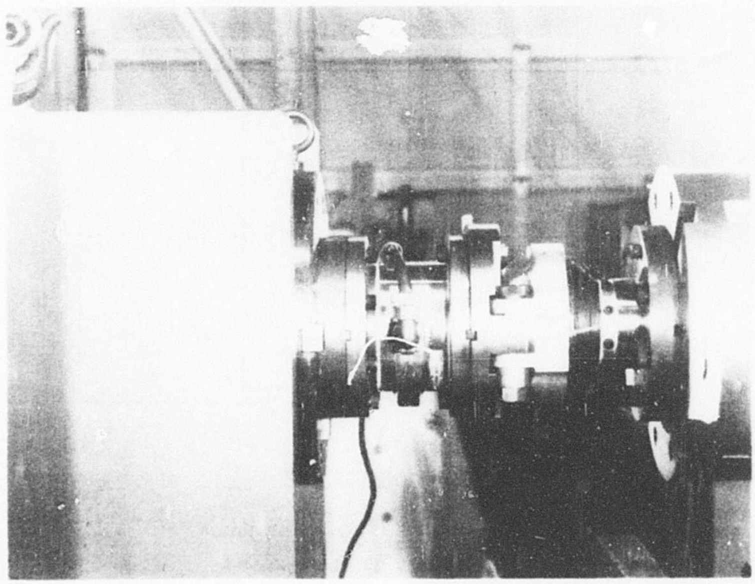


Figure 4. Static Torsional Load Deflection Fixture.

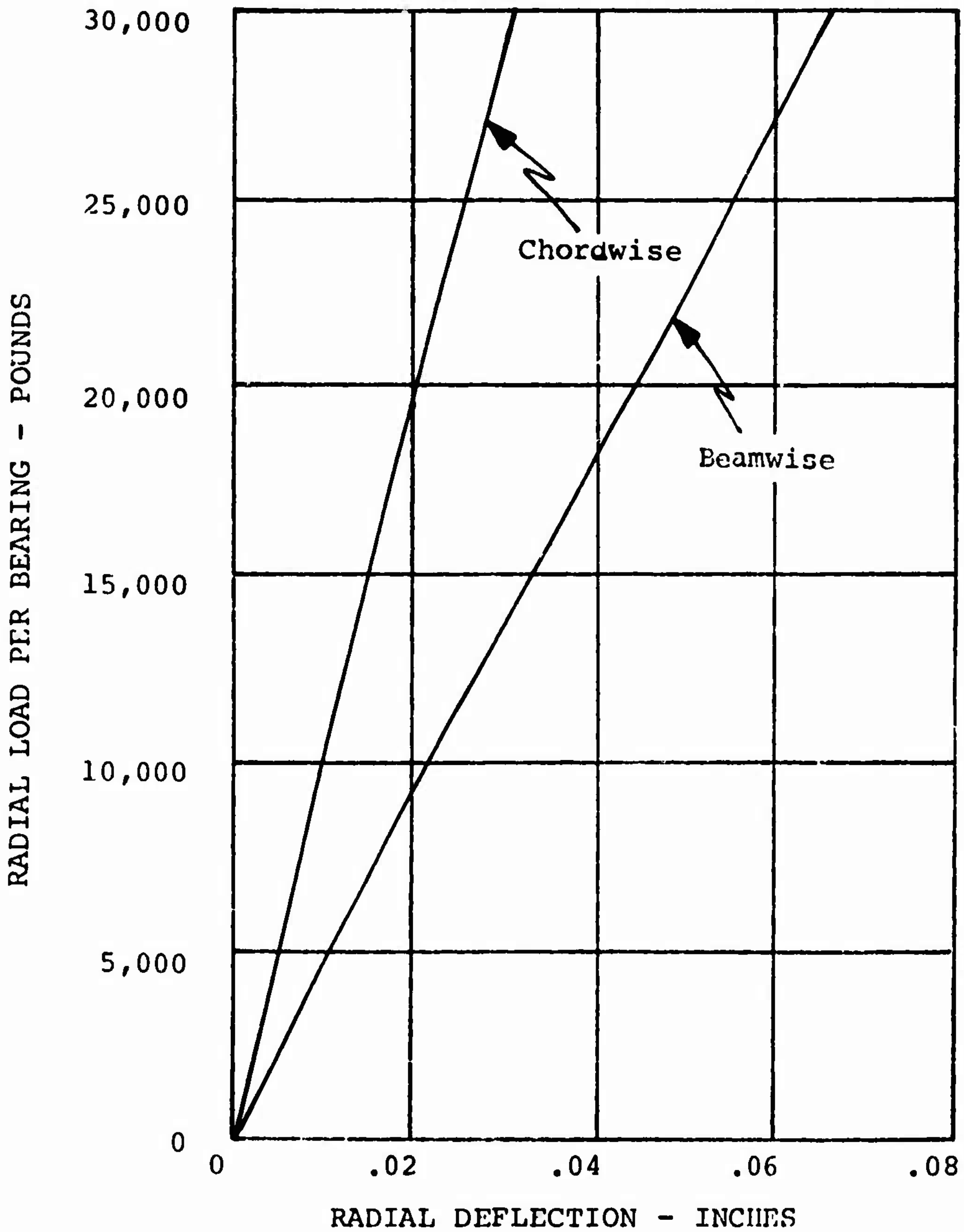


Figure 5. Radial Spring Rate of LM-726-1 With an Axial Load of 56,000 Pounds Imposed (Test Samples 7 and 8).

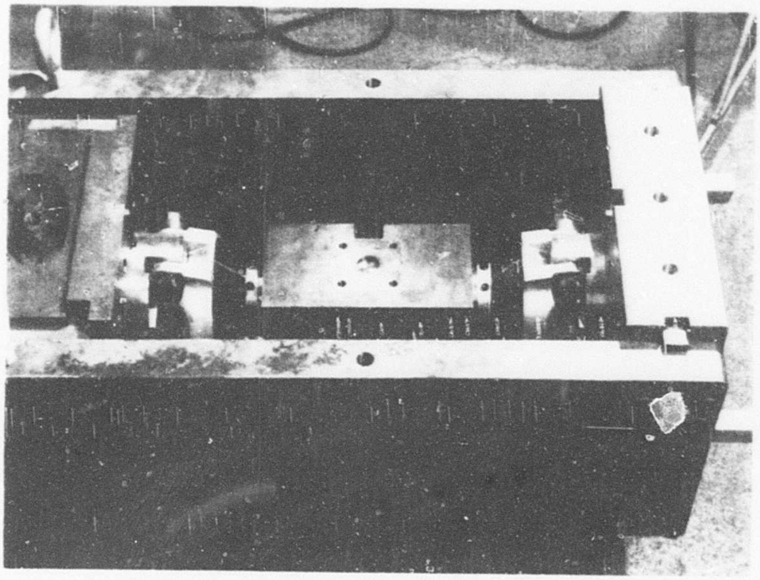


Figure 6. Radial Load Deflection Fixture Prior to Chordwise Radial Test.

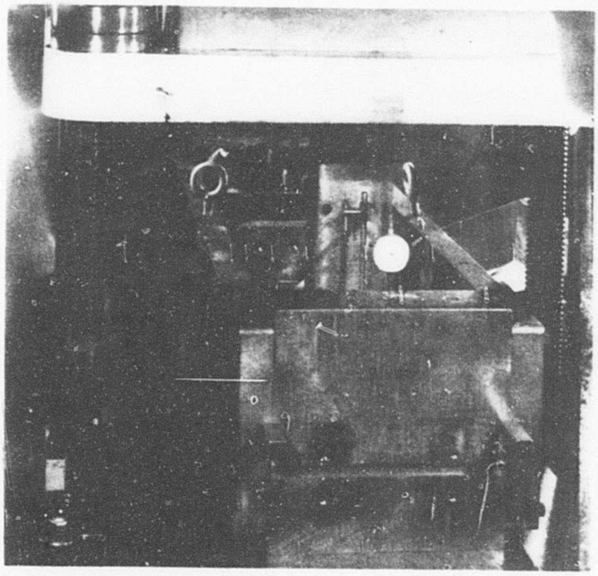


Figure 7. Radial Load Deflection Fixture Installed in Universal Test Machine.

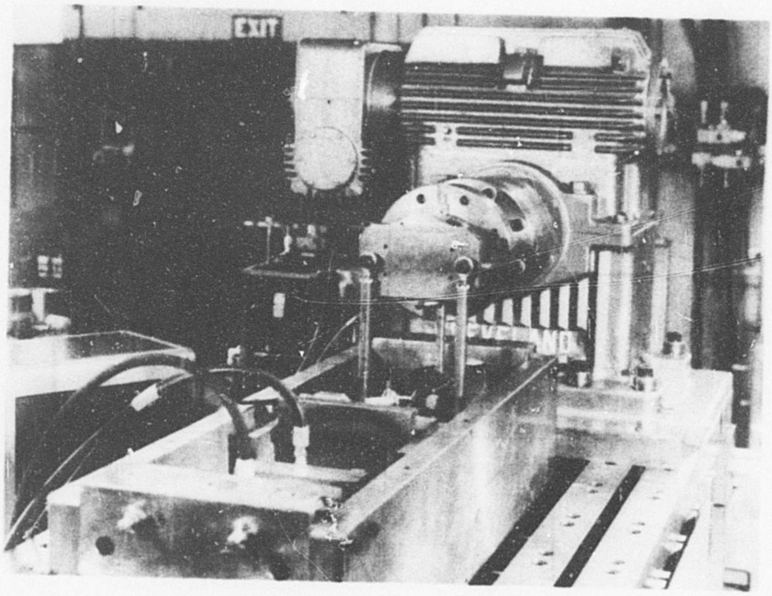


Figure 8. Torsional Test Fixture for
Sample Pairs With Axial Load.

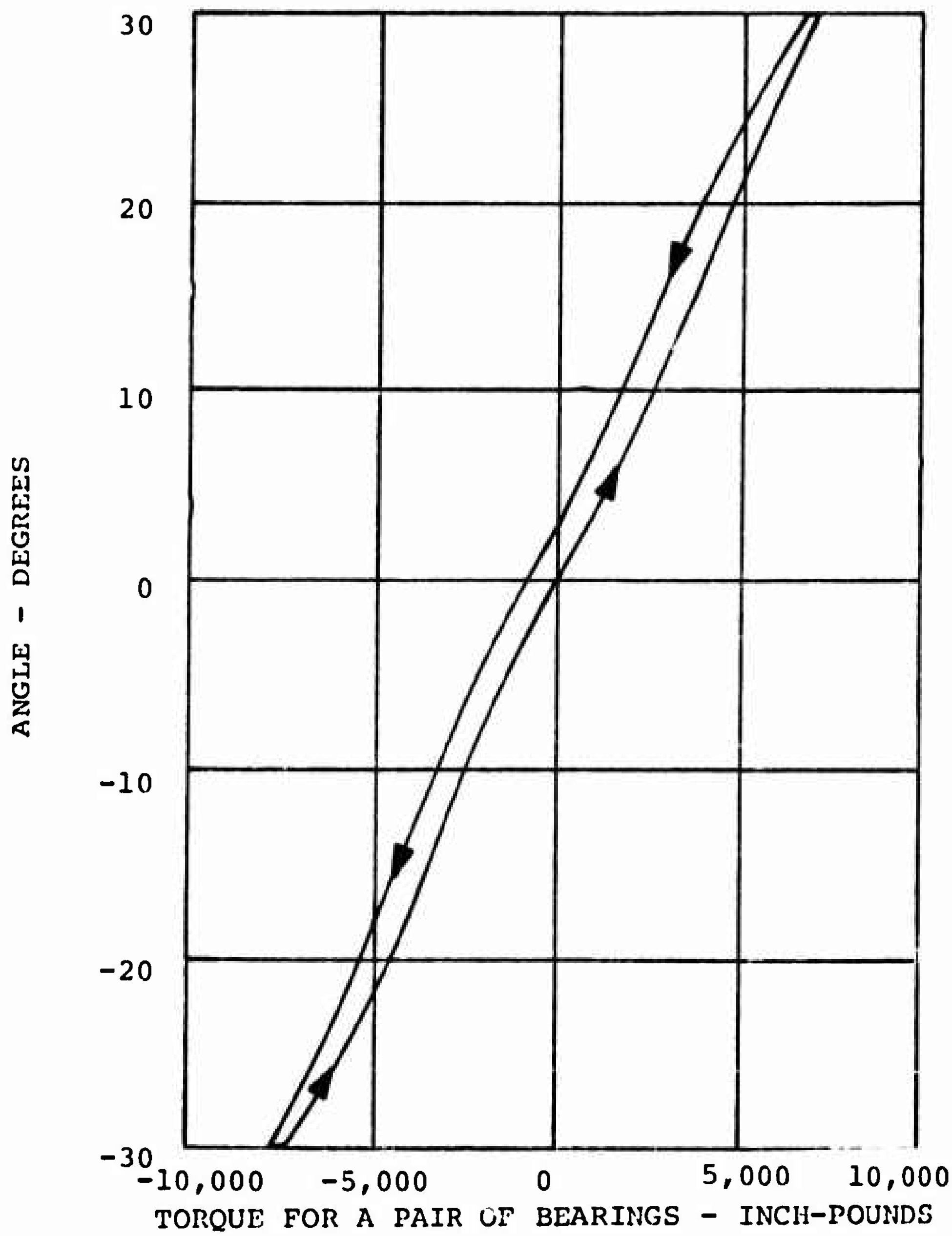


Figure 9. Torsional Spring Rate of New Test Samples 7 and 8 Without Axial Load Imposed (S/N 003 and 008).

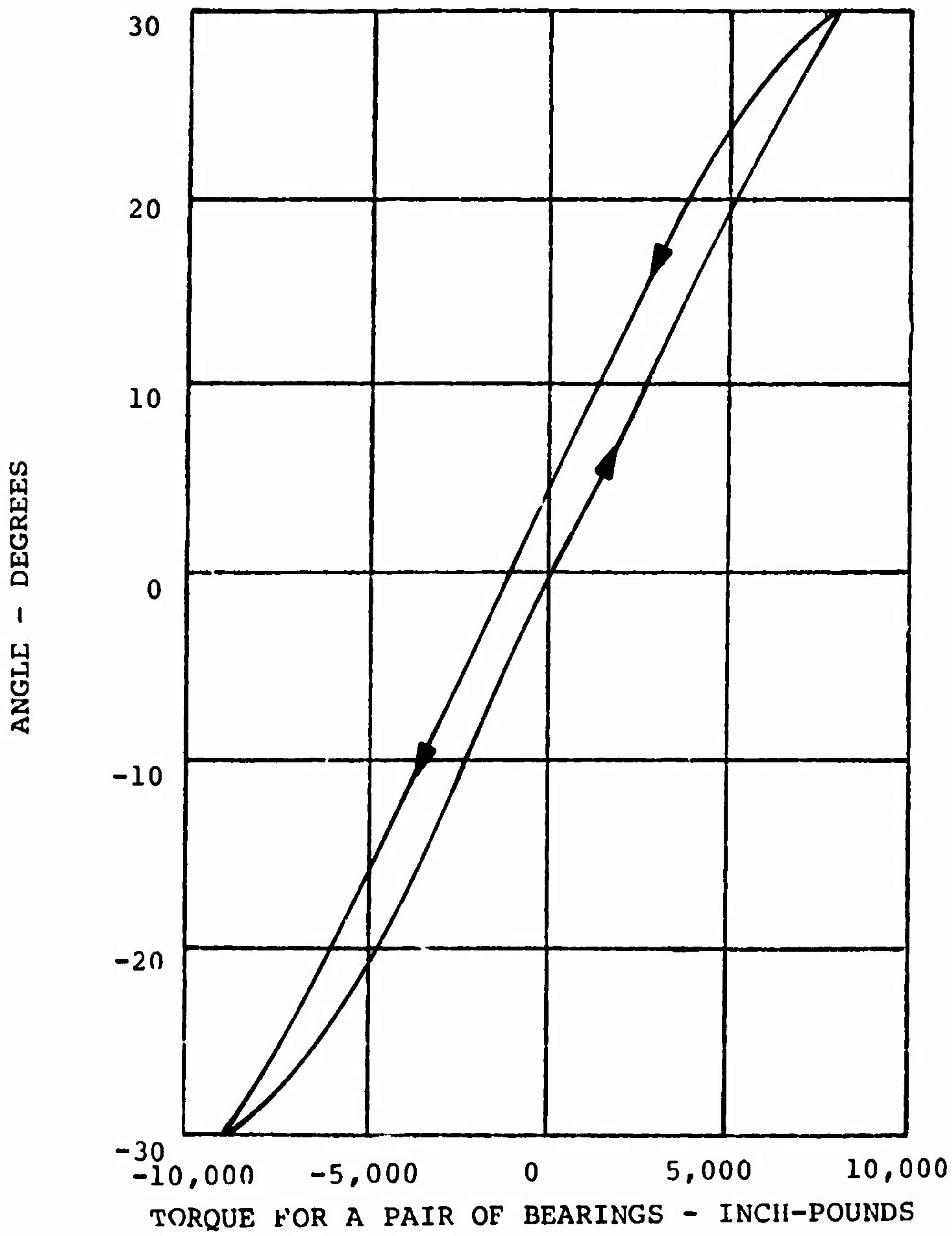


Figure 10. Torsional Spring Rate of New Test Samples 7 and 8 With 56,000 Pounds Axial Load Imposed (S/N 003 and 008).

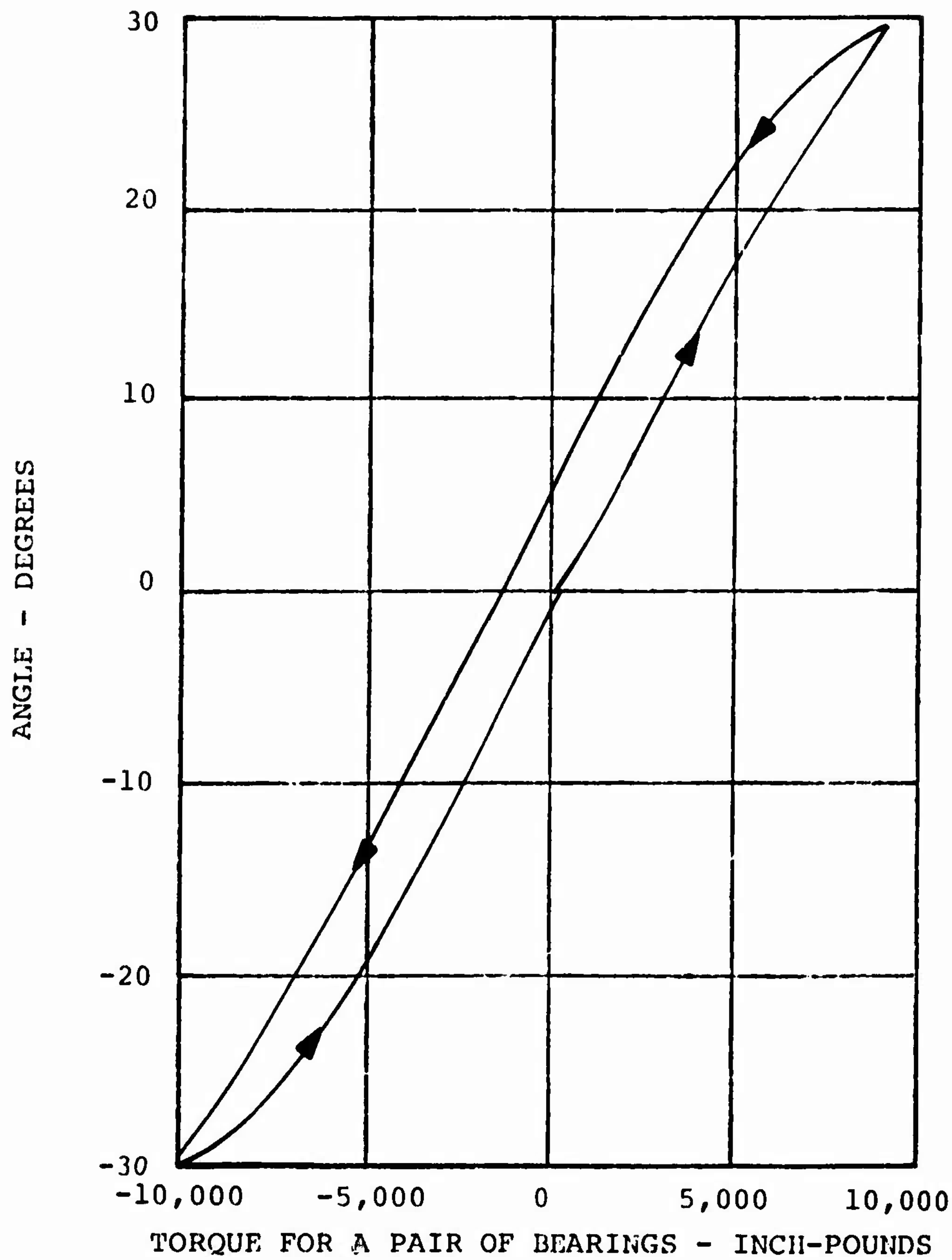


Figure 11. Torsional Spring Rate of New Test Samples 7 and 8 With 84,000 Pounds Axial Load Imposed (S/N 003 and 008).

PRE-ENDURANCE AXIAL FATIGUE

Axial fatigue testing was performed on test samples 7 and 8 while installed in the fixture of Figure 8 as a means of verifying the bearings' predicted performance and suitability for further testing. A hydraulic cylinder was built into the test frame for application of a repeated axial load of 0 pounds to 84,000 pounds at approximately 11 cycles per minute. Dial indicators were used to monitor the axial deflection of each bearing throughout the test. The fixture was designed to allow the performance of torsional load-deflection tests on the bearing pair with various centrifugal force loads applied. A total of 5,000 cycles of loading to 84,000 pounds, representing one and one-half times the normal centrifugal force, was applied.

Table III contains the axial deflection data taken at 1,000 cycle intervals throughout the test. In addition, the appearance of the test samples is described. The torsional spring rates of the test samples through the endurance test are shown in Table IV. The spring rate values are the measured values of the sample pair divided by two to give a sample average.

At the conclusion of the axial fatigue test, the chord-wise radial spring rate of the bearing pair was measured and the results are shown on Figure 12 . Figure 13 contains the axial spring rate of test sample 8 as a new sample and after 5,000 cycles of axial loading. Figure 14 shows test sample 8 at the completion of 5,000 cycles of repeated axial loading. This view of the large end of the sample shows the extrusion and abrasion at the outer-most elastomer layers which was typical of both bearings. The deterioration is most severe directly opposite the attaching lugs, although some abrasion is evident over the entire circumference.

Figure 15 is a view of the small end of test sample 8. Deterioration of this portion of the bearing is similar in nature to that of the large end. Test sample 8 with an 84,000-pound axial load imposed while installed in the test fixture at the completion of 5,000 cycles is shown in Figure 16 .

TABLE III. AXIAL FATIGUE TEST RESULTS

Number of Cycles to 84000 lb	Deflection of T.S. 7 (in.)	Deflection of T.S. 8 (in.)	Remarks on Bearing Condition
0	.128	.139	New samples.
1000	.130	.142	Both samples beginning to extrude elastomer in outer four sections opposite ears on housing.
2000	.133	.145	Extrusion of outer five sections opposite ears.
3000	.137	.149	Extrusion of elastomer continuing. Second section from outside appears worst.
4000	.142	.155	Extrusion of elastomer in outer seven sections. Full circumference of outer two sections is extruding.
5000	.147	.162	Testing completed. Bearings removed from machine for detailed inspection. T.S. 7 and T.S. 8 show equal amounts of deterioration. Outer nine sections show some deterioration at both ends of bearings. Worst deterioration in outer five sections adjacent to ears of outer housing.

TABLE IV. TORSIONAL SPRING RATE DURING AXIAL FATIGUE TEST

No. of Cycles from 0 to 84,000 lb CF	Peak-to-Peak Torque/Peak-to-Peak Defln. (in.-lb/deg) CF = 0 lb	CF = 56K lb	CF = 84K lb
0	125	142	163
1052	118	---	158
2000	117	---	150
3500	115	---	150
5000	112	130	148
	Torque at 15 degrees/15 degrees (in.-lb/deg) CF = 0 lb	CF = 56K lb	CF = 84K lb
0	125	133	143
1052	125	---	142
2000	120	---	137
3500	125	---	140
5000	117	125	137

Note: Data taken on Test Samples 7 and 8 loaded in parallel. Value listed is that for a pair divided by two.

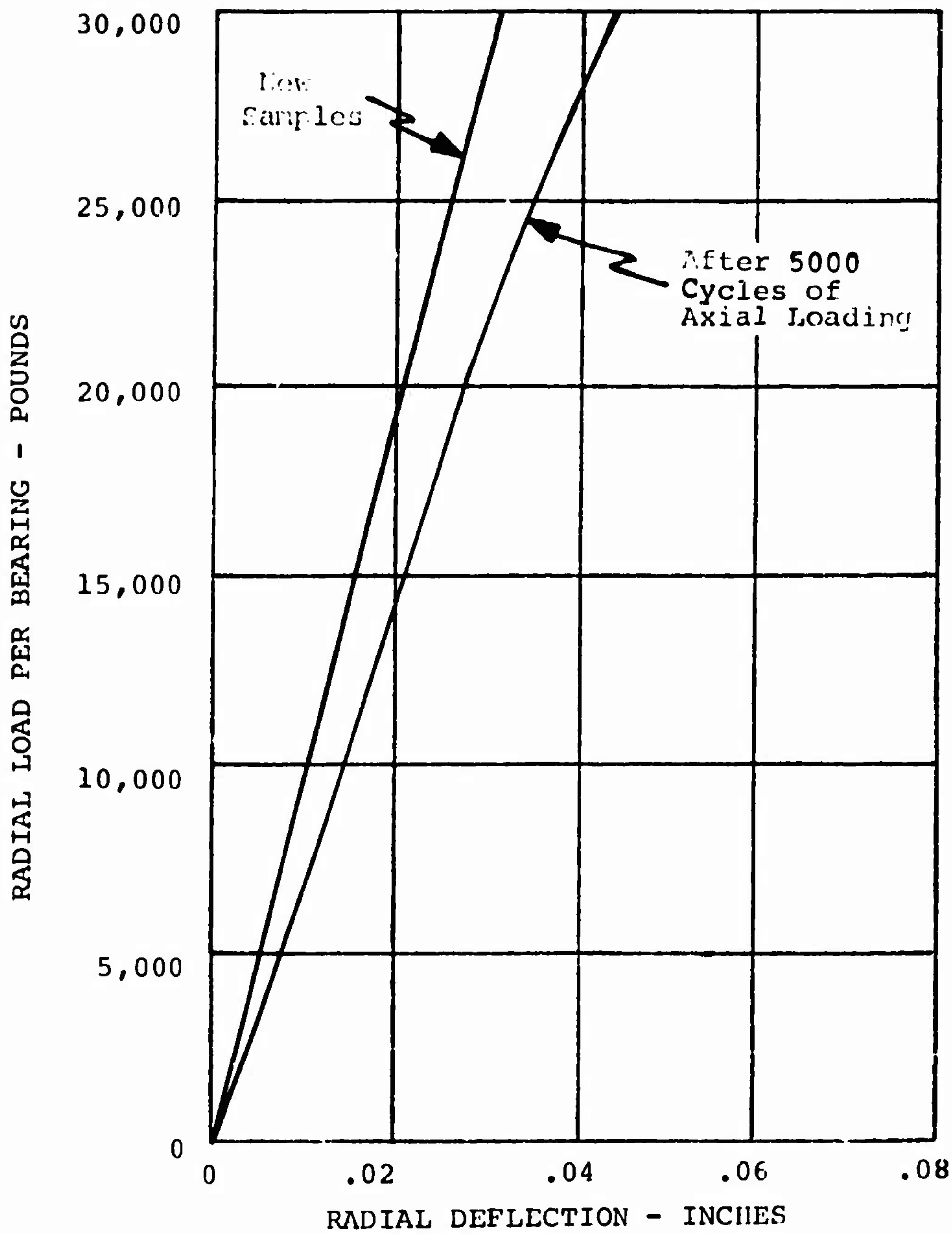


Figure 12. Chordwise Radial Spring Rate of Test Samples 7 and 8 With 56,000 Pounds Axial Load (S/N 003 and 008).

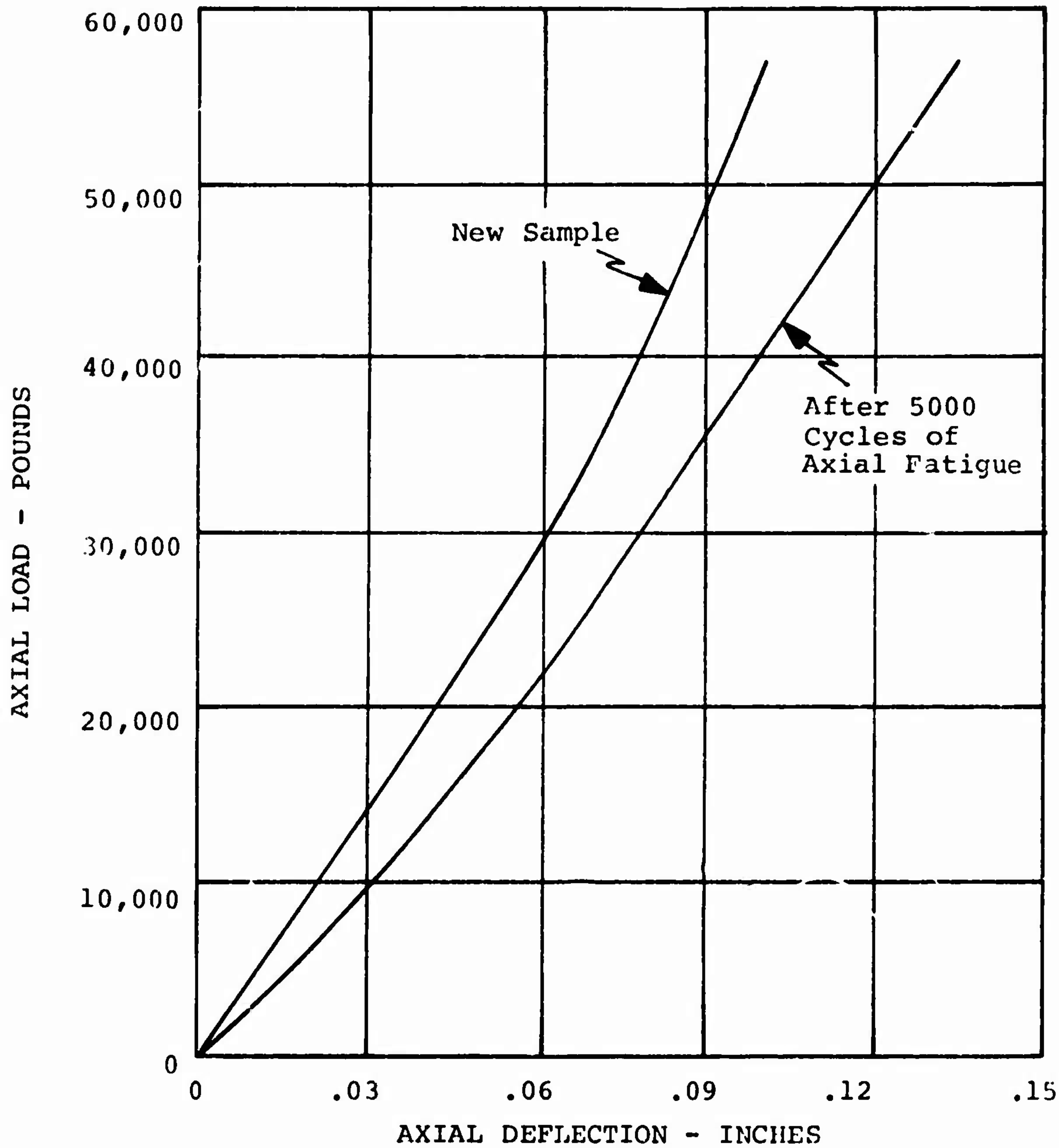


Figure 13. Axial Spring Rate of Test Sample 8, S/N 008.

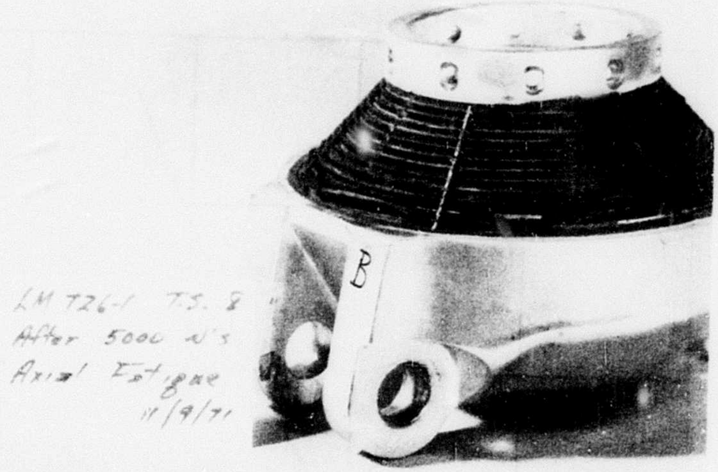


Figure 14. Inboard View of Test Sample 8 After Completion of Axial Fatigue Test.

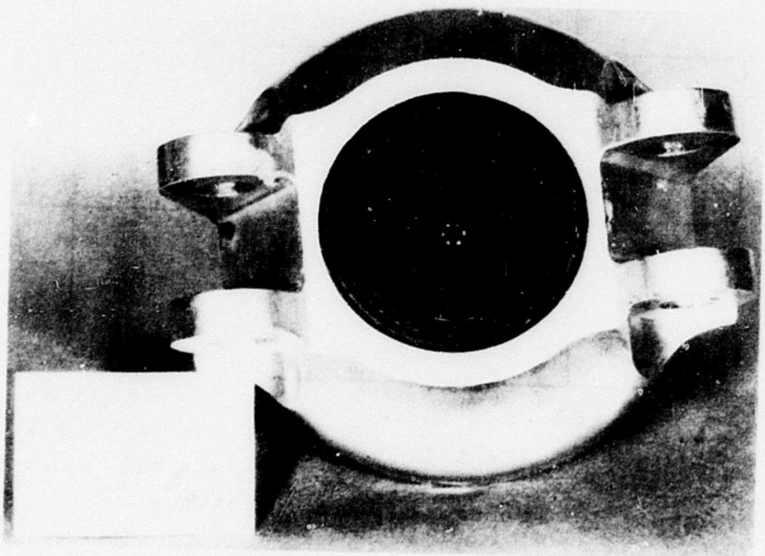


Figure 15. Outboard View of Test Sample 8 After Completion of Axial Fatigue Test.

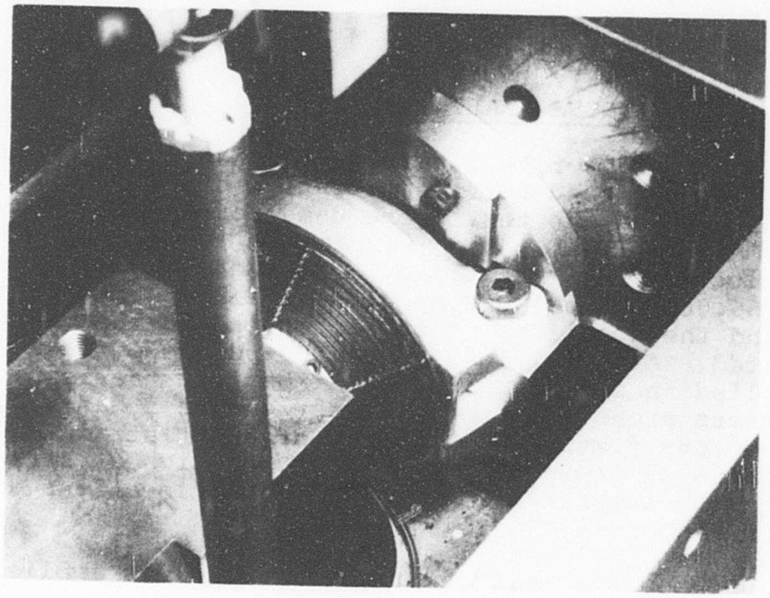


Figure 16. Test Sample 8 After Completion of Axial Fatigue Testing and Under an 84,000-Pound Axial Load.

PRE-ENDURANCE STRESS ANALYSIS

The outer housing of test sample 9 was sprayed with a brittle lacquer used for the detection of stress cracks and installed in the test frame used for axial fatigue tests. Test sample 14, a spare bearing, was installed in a second location in the fixture. The normal centrifugal force (56,000 pounds) was applied axially to the bearing pair, and the locations of stress cracks in the coating were noted. A radial load of 30,000 pounds per bearing was applied in the beamwise direction, and the resulting high stress areas were noted. Test sample 9 was removed from the test fixture and a total of eight strain gages were placed as close as possible to the highest stressed areas on the outer housing. Strain gage locations are shown in Figures 17, 18, 19, and 20.

The 56,000-pound normal centrifugal force was applied to the strain-gaged bearing, and the results are contained in Figure 21. At the completion of the axial load test, test sample 9 was re-installed in the test frame with test sample 14. The normal centrifugal force load was applied to the bearings and the resulting stress recorded. The gages were then monitored while a 30,000-pound radial load was superimposed on each bearing. The resulting stress measurements are shown in Figure 22.

Test sample 9 was removed from the test fixture and placed in a universal test machine with a load capacity of 200,000 pounds. Strain gage readings were taken at 20,000-pound intervals up to an axial load of 180,000 pounds. The inability of the test machine to maintain a constant 200,000 pounds prevented the obtaining of stress measurements at that load level. However, the bearing successfully withstood the 200,000-pound load with no apparent damage either to the elastomer or to the metal components. The stress data obtained is shown in Figure 23.

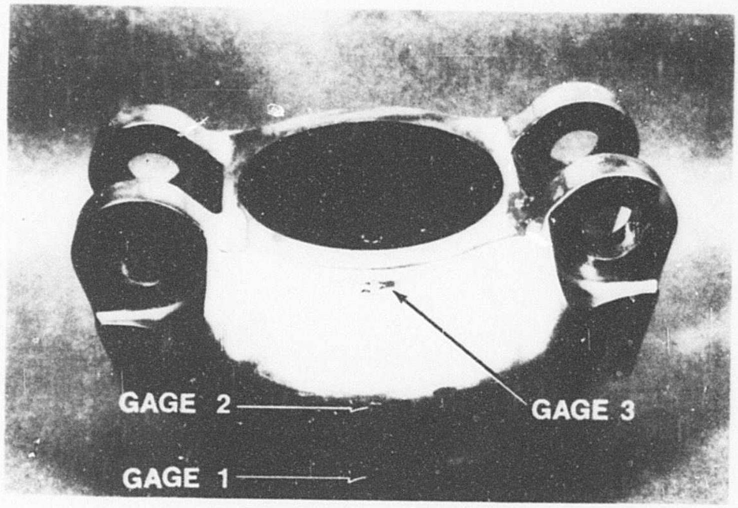


Figure 17. Location of Strain Gages 1, 2, and 3.

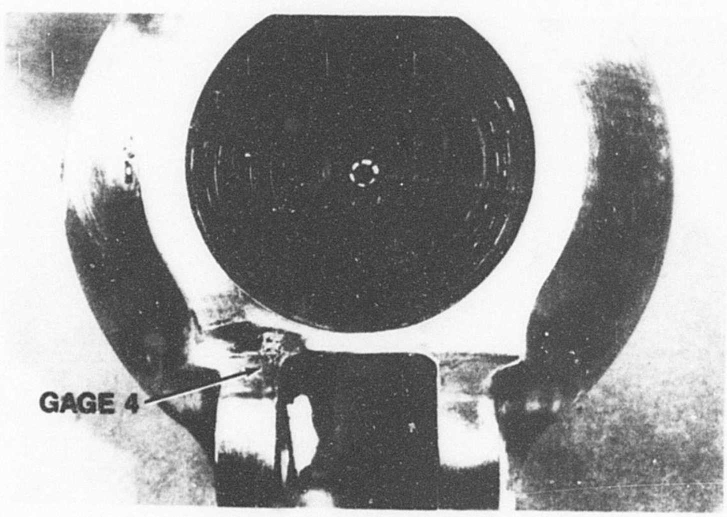


Figure 18. Location of Strain Gage 4.

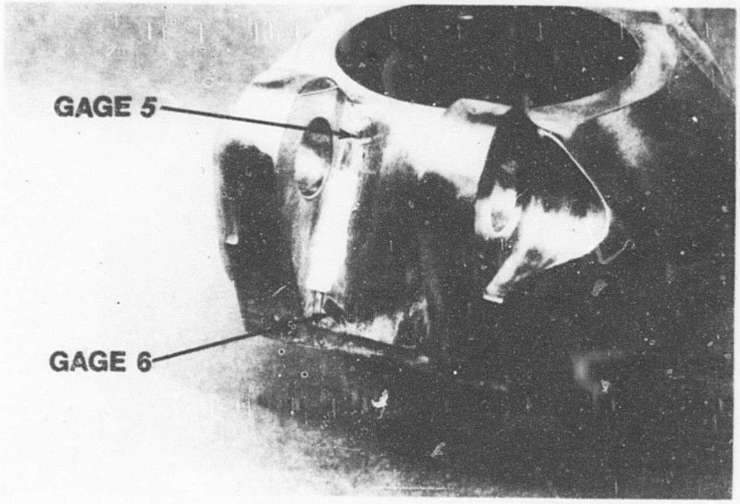


Figure 19. Location of Strain Gages 5 and 6.

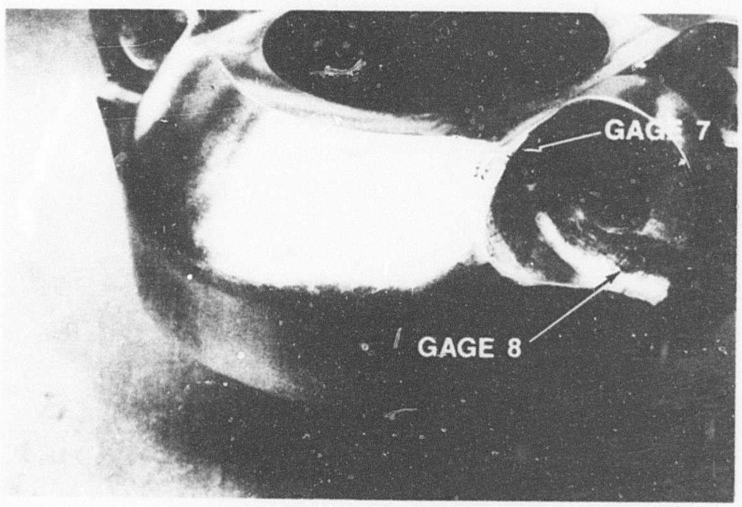


Figure 20. Location of Strain Gages 7 and 8.

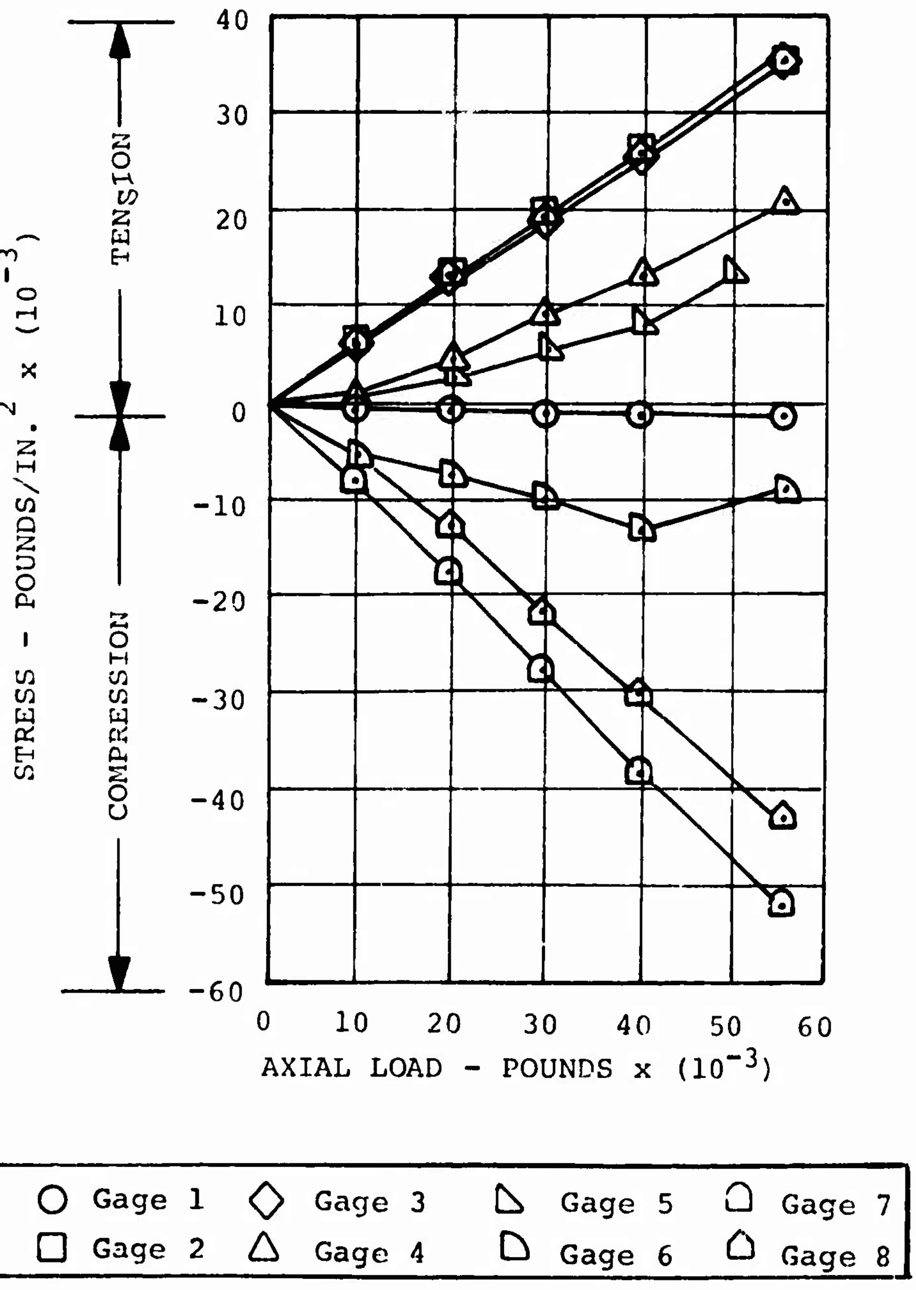


Figure 21. Outer Housing Stress Due To Normal Axial Loads.

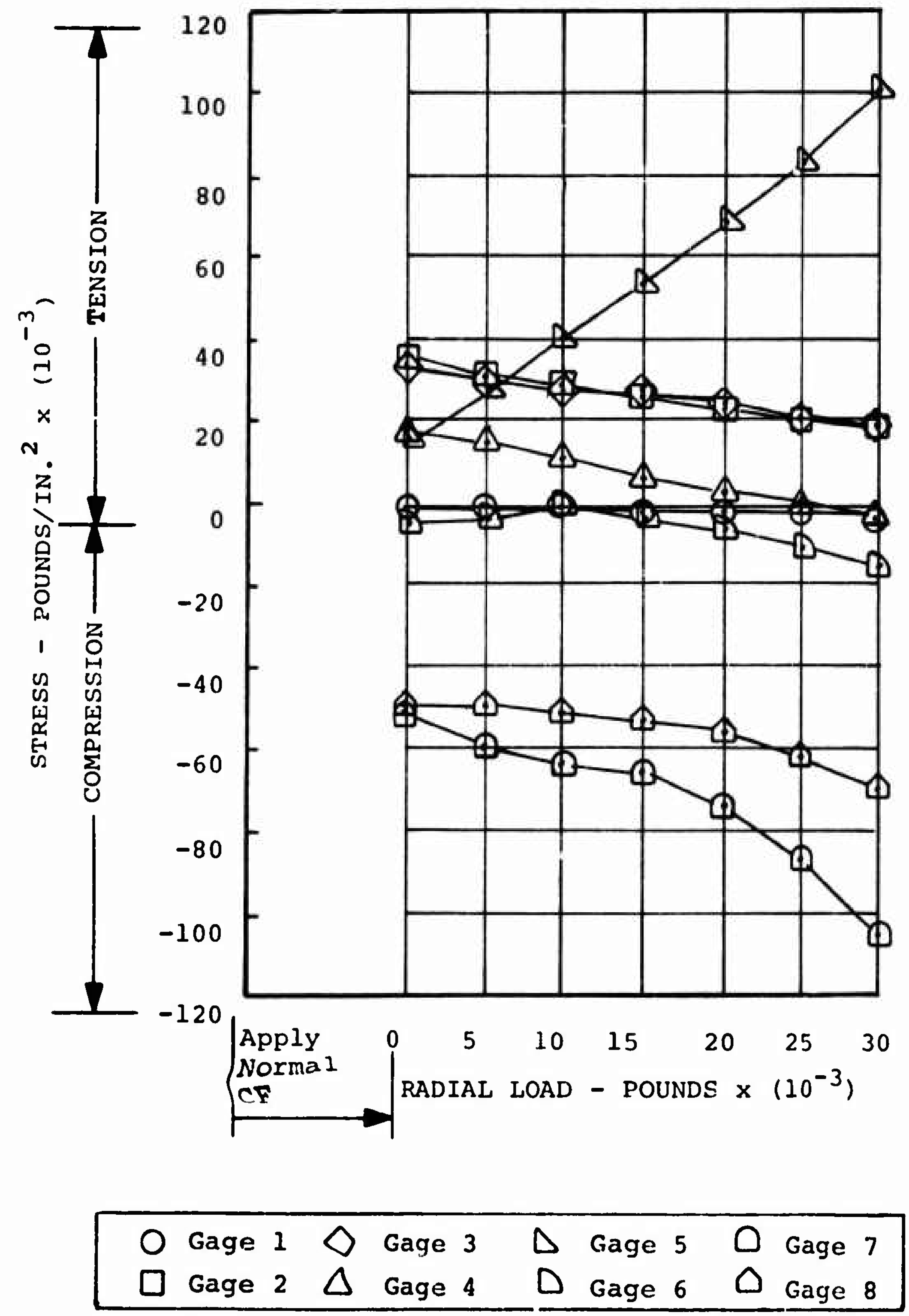


Figure 22. Outer Housing Stress Due To Combined Axial and Radial Loads.

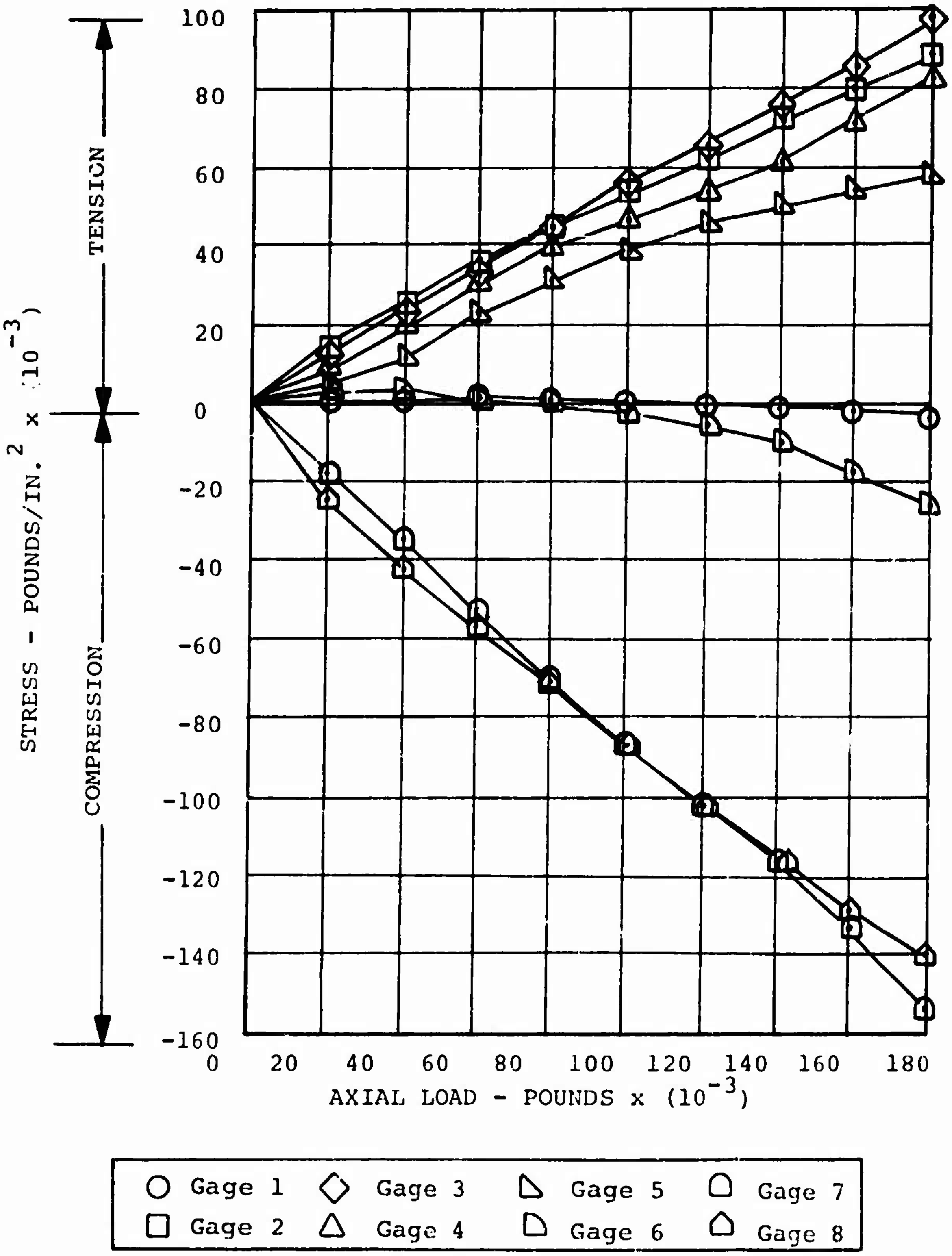


Figure 23. Outer Housing Stress Due To Ultimate Axial Load.

ENDURANCE TESTING

INTRODUCTION

Endurance testing of the LM-726-1 bearing imposed simulated service load and motion conditions on three pairs of test samples. A special test machine was designed and fabricated with the capability of applying a steady centrifugal force on the bearings with simultaneous steady and oscillatory radial loads in the chordwise direction. In addition, steady and oscillatory torsional pitch change motion was applied in phase with the radial loading. The load and motion spectrum shown in Table V was based on actual in-flight measurements of a conventional Model 540 rotor and an all-elastomeric Model 540 rotor with LM-726-1 bearings installed.

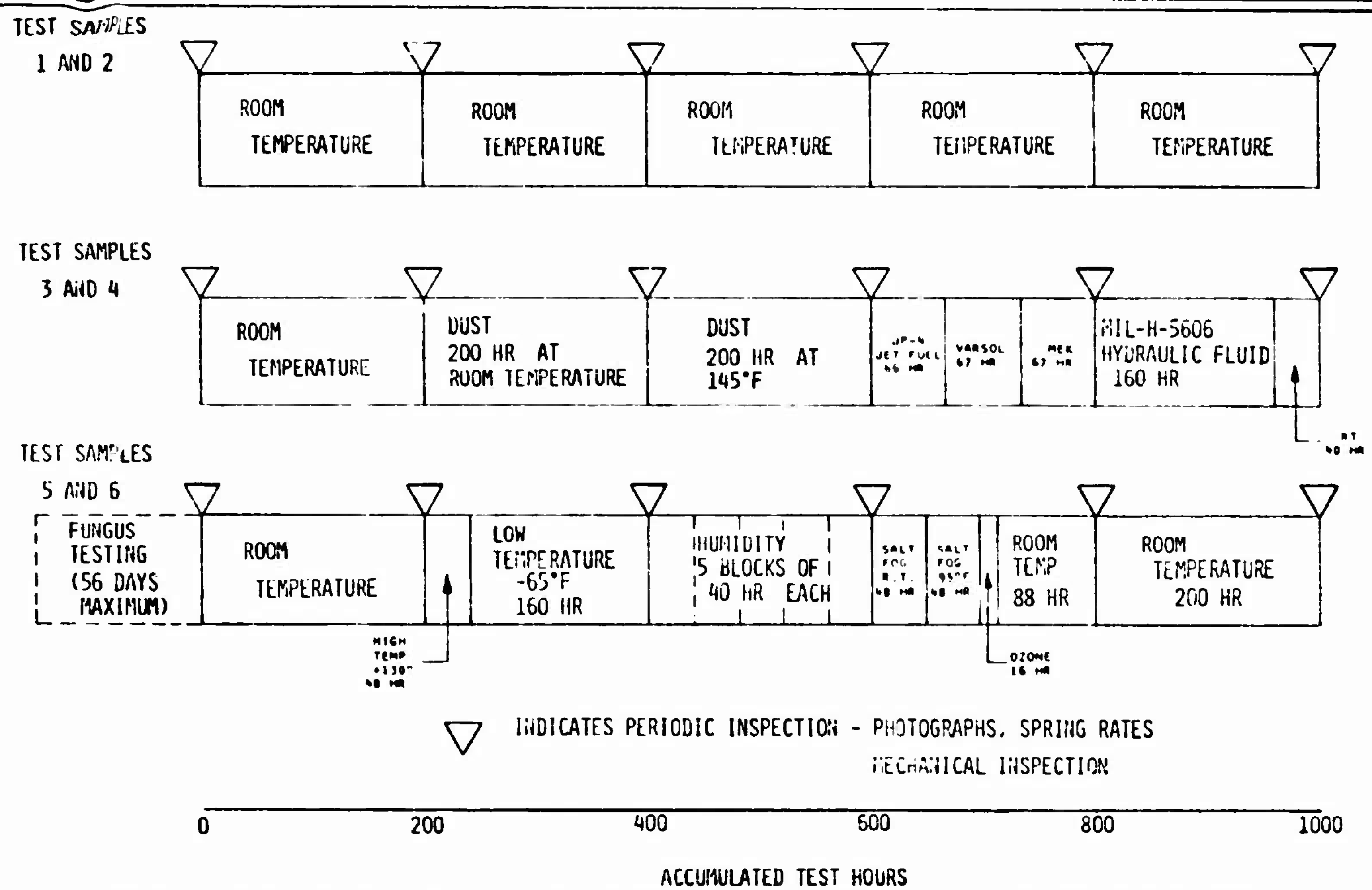
Environmental conditions, typical of helicopter service, were imposed on two of the bearing sets simultaneous with the load and motion inputs. The remaining set was not subject to any adverse environment and served the purpose of a standard for comparison. The environmental conditions were applied in accordance with the breakdown of Table VI. At 200-hour intervals throughout the test, periodic testing was performed on the bearings as a means of monitoring their condition. These tests, performed on the bearings after removal from the test machine, consisted of axial and torsional static load-deflection tests, dimensional inspections, and visual inspection with photographs. In addition to the scheduled periodic inspections, the appearance of the test samples was monitored throughout the test. Detailed inspection of the bearings while installed in the test machine was difficult, particularly during environmental conditions which required enclosures.

Endurance testing was performed at Wyle Laboratories, Huntsville, Alabama, in accordance with Lord Manufacturing Company Test Plan 8B035 (see appendix). All test fixture design and fabrication was approved, and selected portions of the testing were witnessed by Lord Engineering representatives.

TABLE V. LOADS AND MOTIONS FOR ENVIRONMENTAL ENDURANCE TEST

Cond. No.	Test Seq.	Pct. Occur.	Axial Load (lb)	Radial Load (lb) Steady	Radial Load (lb) Osc.	Pitch Motion (deg) Steady	Pitch Motion (deg) Osc.	Dynamic Freq. (cpm)
1	5	0.25	56,000	10000	± 9400	14	± 9.5	324
2	7	6.75	56,000	9000	± 8000	4	± 9.5	324
3	2	2.00	56,000	7000	± 6500	4	± 9.5	324
4	6	22.50	56,000	6000	± 5000	2	± 8.2	324
5	3	22.00	56,000	4000	± 3600	2	± 7.0	324
6	1	32.00	56,000	3000	± 2200	0	± 5.7	324
7	4	14.50	56,000	2000	± 2200	6	± 3.2	324
--	--	800 cycles	0	2640	----	0	± 12	5
--	--	800 cycles	0/56000/0	0	0	0	0	5

TABLE VI. ENVIRONMENTAL EXPOSURE BREAKDOWN FOR LM-726-1 ENDURANCE TEST



NOTE: TESTING BEYOND 1,000 HOURS WAS PERFORMED AT ROOM TEMPERATURE

ENDURANCE TEST MACHINES

The test machine used for the application of the endurance test conditions is shown in Figure 24. Two of the three test stations, each station accommodating two test samples, are shown in this photograph. The centrifugal force axis is in line with the beam running from the lower left corner to the upper right corner. The radial load actuators are perpendicular to this beam. A close-up of a single station is shown in Figure 25. The hydraulic cylinder for the application of centrifugal force is attached to the sample outer member. Two radial load actuators are visible in the foreground of the photograph, one cylinder for each test sample. The pitch change actuator is between the two radial load cylinders and is angled upward.

The static load-deflection tests included as part of the periodic tests were performed in test fixtures similar to those used for pre-endurance spring rate testing. Prior to approval of the periodic test fixtures, the data obtained was compared to the previously obtained pre-endurance data. Torsional data obtained on the two sets of fixtures was identical. However, the fixture used for the axial test during the periodics resulted in a spring rate approximately 25% stiffer than the value obtained during pre-endurance. This difference was attributed to an improved means of measuring the axial deflection, and the fixture was approved for use in monitoring axial spring rate.

FUNGUS TESTING

Prior to endurance testing with simulated load and motion conditions imposed on the test samples, test samples 5 and 6 completed a static fungus test performed in accordance with MIL-STD-810B, Method 508. The test samples, along with susceptible substrates as control items, were inoculated and allowed to remain in the test chamber for 14 days. Inspection at 14 days revealed that abundant growth had not occurred on either the samples or the control items. New control items and the test samples were re-inoculated and allowed to remain on test for an additional 14 days. At this time, inspection indicated abundant growth on the control items, and the test was allowed to continue to the full 28 days specified in the procedure. Inspection at the completion of 28 days revealed abundant growth on the control items, but the LM-726-1 test specimens did not support fungus growth.

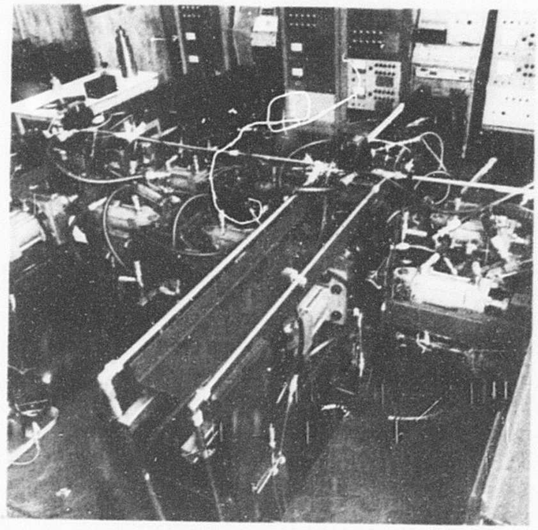


Figure 24. Endurance Test Machine.

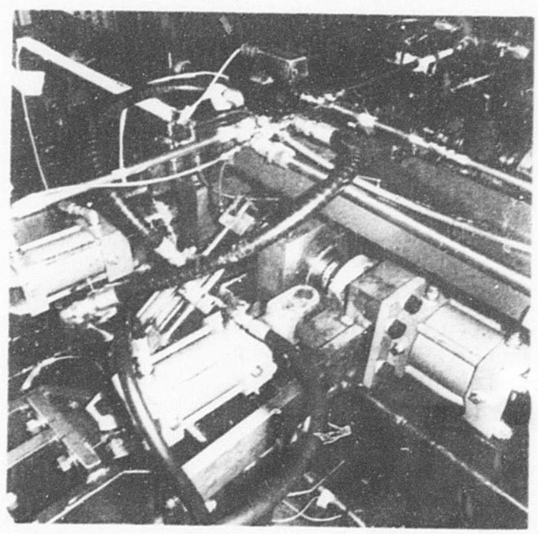


Figure 25. Endurance Test Station.

ENDURANCE TEST PROCEDURE

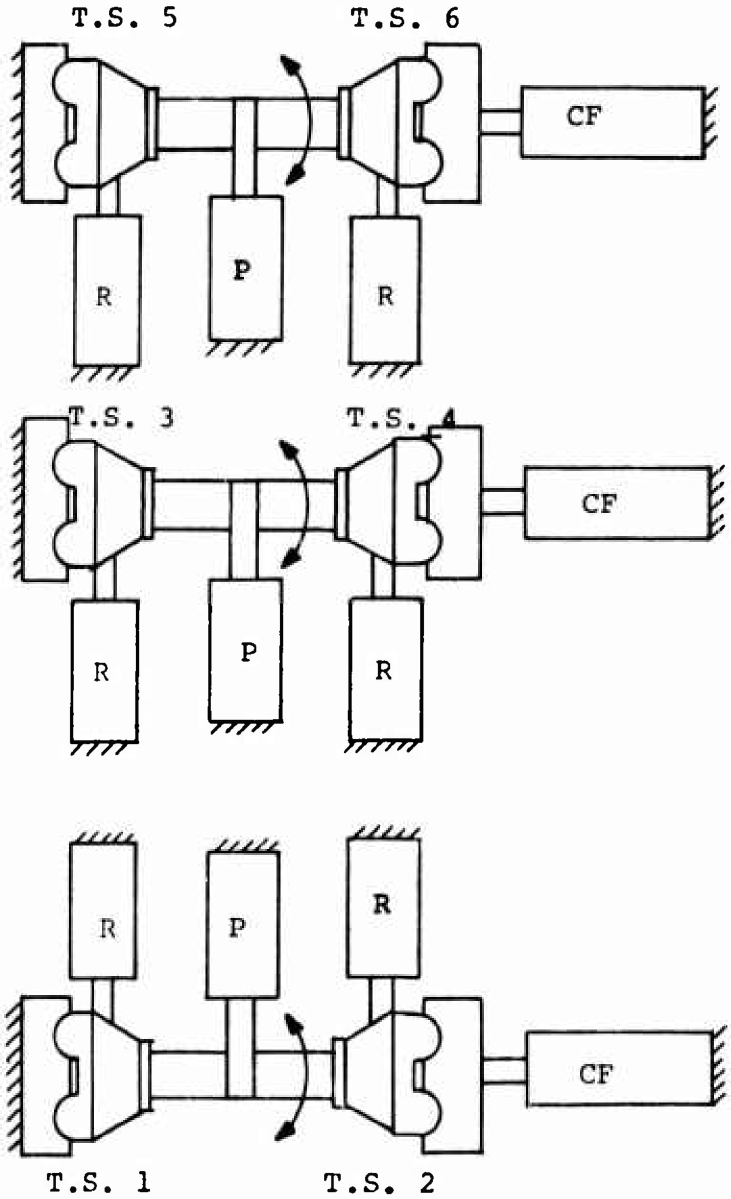
Upon completion of the "zerc" hour periodic test, test samples 1 through 6 were installed in pairs at the three independent test stations as shown in Figure 26. A test spectrum recycling block of 40 hours was established as the best compromise between testing convenience and the attempt to duplicate an actual flight duration. The sequence of testing was as shown in Table V and was established to minimize internal heating of the test bearings.

In actual flight, conditions with a relatively high input which results in internal hysteresis heating of the bearings are of short duration such that heating is minimized. In addition, a considerable amount of cooling air flows across the bearings due to the rotor air flow characteristics. The test sequence was selected such that conditions which generate considerable heat are not in sequence, but are followed by less severe conditions which allow the bearing to cool. Small fans were installed at each test station to simulate rotor-induced air flow.

Prior to the initiation of endurance test cycling, static and dynamic spring rate tests were performed on the sample pairs while installed in the test machine. Testing the bearings in pairs was a means of obtaining the capability of performing torsional and radial load-deflection tests with the normal centrifugal force applied.

The static torsional test was performed with a constant 56,000-pound axial load and a torsional input from the zero angle to a 20° input in both directions at a rate of 20° per minute. The dynamic torsional input was ± 12° at a frequency of 324 cycles per minute with a constant 56,000-pound axial load.

During the static radial load-deflection test, the test sample pair was loaded from 0 to 12,000 pounds per bearing at a rate of .02 inch per minute. The centrifugal force of 56,000 pounds was maintained during this test. The dynamic radial test imposed a steady 9,000-pound radial load with an alternating 8,000-pound load at 324 cycles per minute with the 56,000-pound centrifugal force applied. All dynamic tests were performed after approximately 1 minute of cycling at the specified input condition.



CF - Centrifugal Force
R - Radial Load
P - Pitch Motion

Figure 26. Location of Test Samples in Endurance Test Machine.

Endurance test cycling began after the completion of all "zero" hour periodic tests. The initial 200 hours of testing was performed with all six test samples at room temperature. At the completion of 200 hours of endurance cycling, the manual conditions listed in Table V were applied.

The first manual condition listed represents extreme pitch change motion applied with no centrifugal force to simulate an on-ground controls checkout. The second manual condition simulates rotor startup to full rotor speed and subsequent shutdown.

Upon completion of the manual conditions, the first 200-hour periodic test was begun. Prior to removal of the test specimens, the torsional and radial load-deflection tests on sample pairs were completed. The test samples were then removed and the static torsional and axial load-deflection tests on the individual samples were performed.

The static torsional test consisted of an input from 0 degrees to -20 degrees back through 0 degrees to +20 degrees and returning to the original position. This test was performed without axial load on the bearing at a loading speed of 20 degrees per minute. The axial test consisted of a 0- to 56,000-pound loading in the centrifugal force direction at .125 inch per minute.

Each sample was then photographed and dimensionally inspected in accordance with the test plan. The dimensions inspected were selected to determine changes in the flexing element as well as the major metal components.

The test samples were then re-installed in the test machine at the same location and in the identical orientation for continuation of the test. Testing was continued with the specified environmental conditions until the next scheduled periodic at the 400-hour level.

The failure criterion for the test samples was arbitrarily established as a 40% decrease in static torsional spring rate from the zero hour value. Among the other criteria for failure were broken shims, inability to support radial or axial loads, excessive loss of elastomer resulting in heat buildup, and failure of a major metal component.

A considerable decrease in the static torsional spring rate of all six samples was noticed at the 400-hour level. The rate of decrease from the 200-hour level indicated that the test bearings would exceed the allowable decrease in spring rate prior to the next scheduled periodic at 600 hours. For this reason, an additional periodic was scheduled at the 500-hour level. The torsional spring rates obtained at 500 hours were in all cases higher than the 400-hour data and at a level indicating a more gradual failure rate than anticipated. Data obtained at 500 hours, as well as succeeding data, indicates that the 400-hour data was in error and should be ignored. After completion of the 500-hour periodic, the previously established schedule for periodics was reinstated.

A modification of the original contract allowed extension of the endurance test beyond the originally scheduled 1000 hours until all of the original six samples were failed. As a result, testing continued to the 1400-hour level. Two spare samples were available and were required as substitutes for failed bearings. These spares received the same inspections as the original six samples. In addition, a "dummy" bearing with an undetermined load history was inserted, but its condition was not monitored.

ENDURANCE TEST RESULTS

PERIODIC STATIC SPRING RATES OF INDIVIDUAL SAMPLES

The results of the periodic torsional and axial spring rate tests for the six original samples and the two spares are contained in Figures 27 through 42. The value shown for the torsional spring rate is the peak-to-peak torque divided by the peak-to-peak deflection of 40°. The axial spring rate value was obtained by dividing the normal centrifugal force load of 56,000 pounds by the deflection obtained at that load.

Both torsional and axial spring rates decrease as the endurance test hours increase as a result of the gradual loss of elastomer due to fatigue. All test samples appear to decrease in spring rate at a similar rate despite the varying environmental exposure. Figures 43 and 44 illustrate the torsional and axial spring rate envelopes of test samples 1 through 6 throughout the endurance test. All six samples were grouped closely, indicating a consistent rate of degradation.

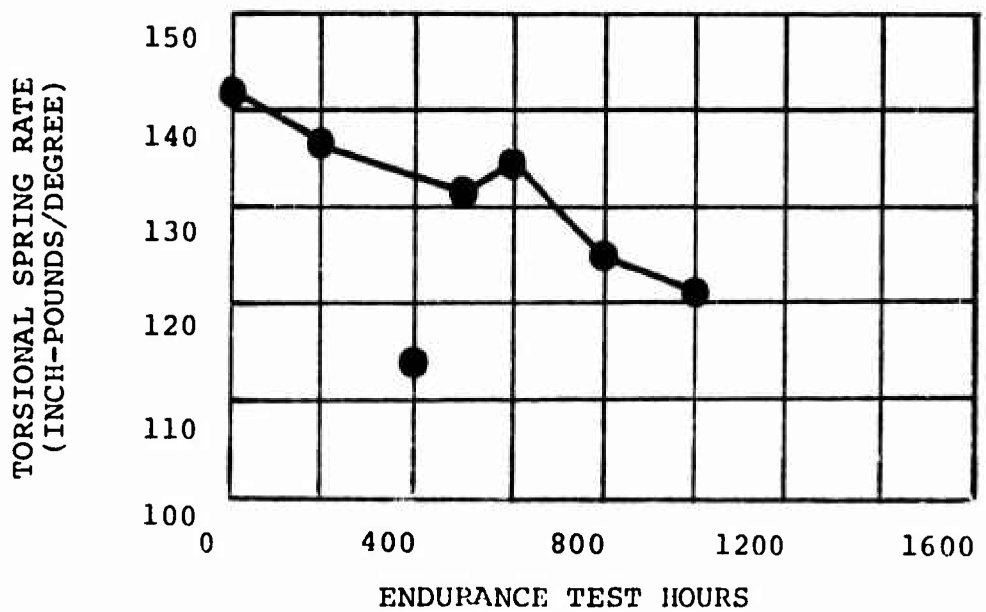
PERIODIC STATIC TORSIONAL SPRING RATES OF SAMPLE PAIRS

The static torsional spring rates of test sample pairs obtained during the periodic tests are contained in Table VII. These spring rates were obtained on the samples while installed in the endurance test machine with the normal centrifugal force applied. The values shown include an unknown amount of friction from the test machine bearings which affects the accuracy of the data. However, the general trend of increasing spring rate is believed to be valid.

Experience gained from similar tests indicates that the torsional spring rate under an axial load will eventually decrease. However, the torsional spring rate without the axial load imposed is more sensitive to bearing degradation, and is therefore a better means of monitoring failure.

PERIODIC DYNAMIC TORSIONAL SPRING RATES OF SAMPLE PAIRS

Table VIII contains the dynamic torsional spring rates of the test sample pairs measured in the endurance test machine. This data was also obtained with the centrifugal force applied and illustrates the same trend as the static data.



<u>Note</u>: Tests performed without axial load applied.

Figure 27. Static Torsional Spring Rate of Test Sample 1 (S/N 001).

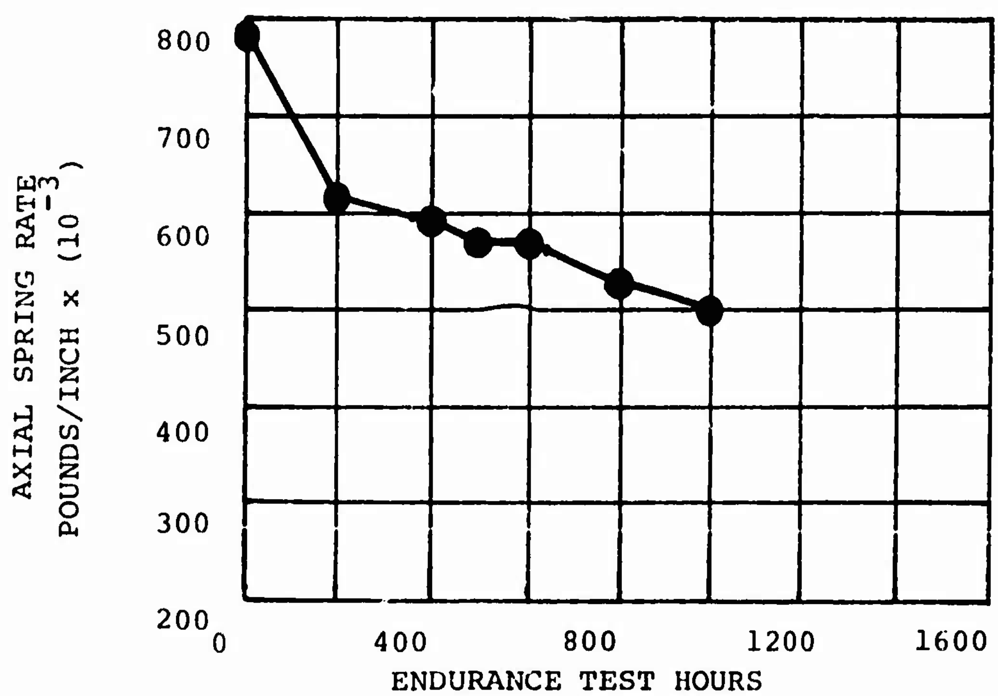
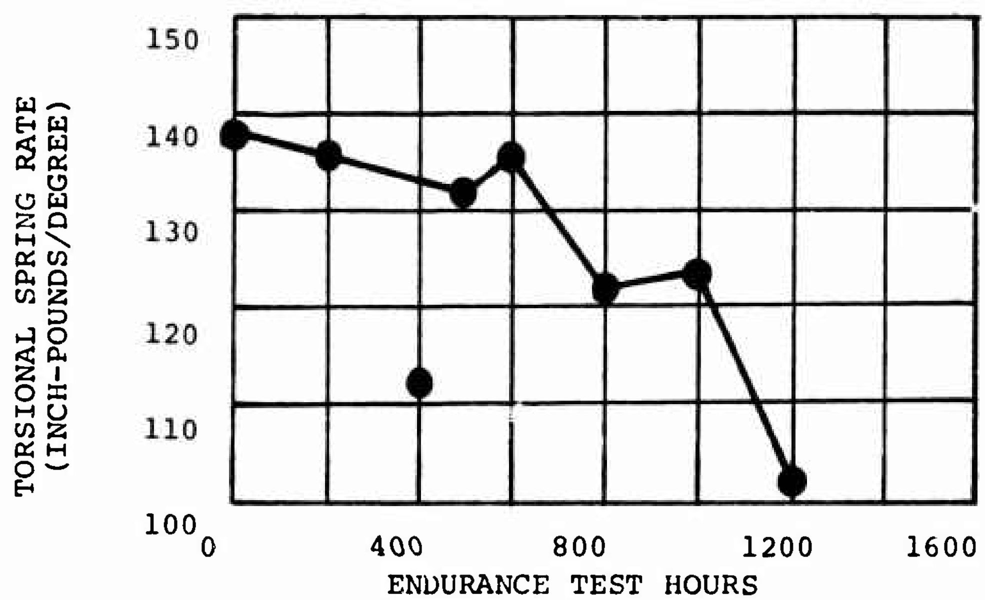


Figure 28. Static Axial Spring Rate of Test Sample 1 (S/N 001).



Note: Tests performed without axial load applied.

Figure 29. Static Torsional Spring Rate of Test Sample 2 (S/N 002).

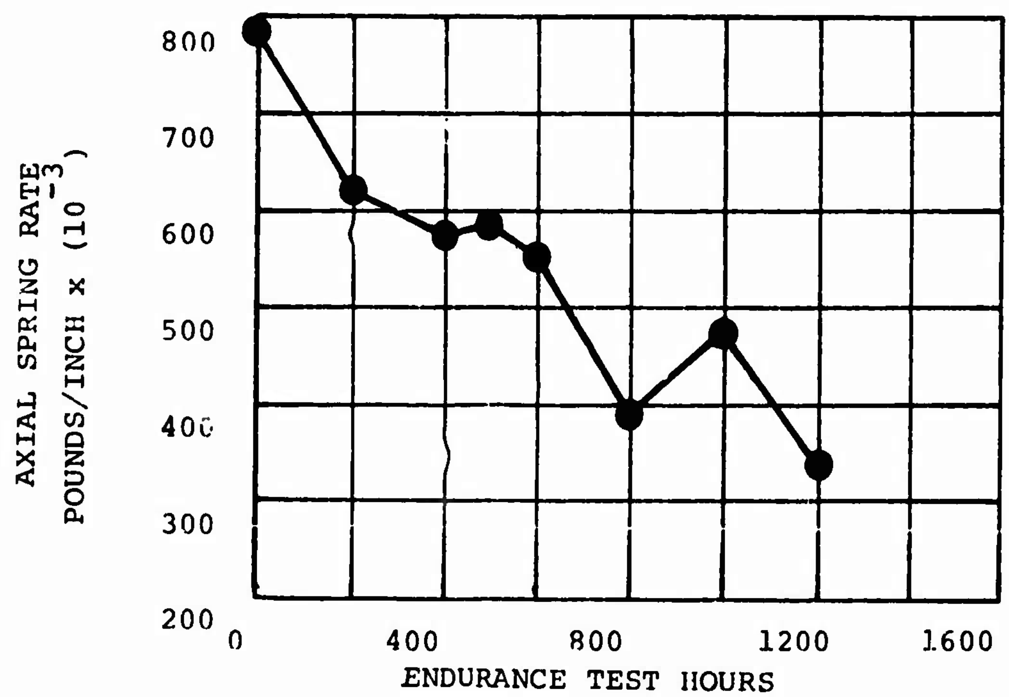
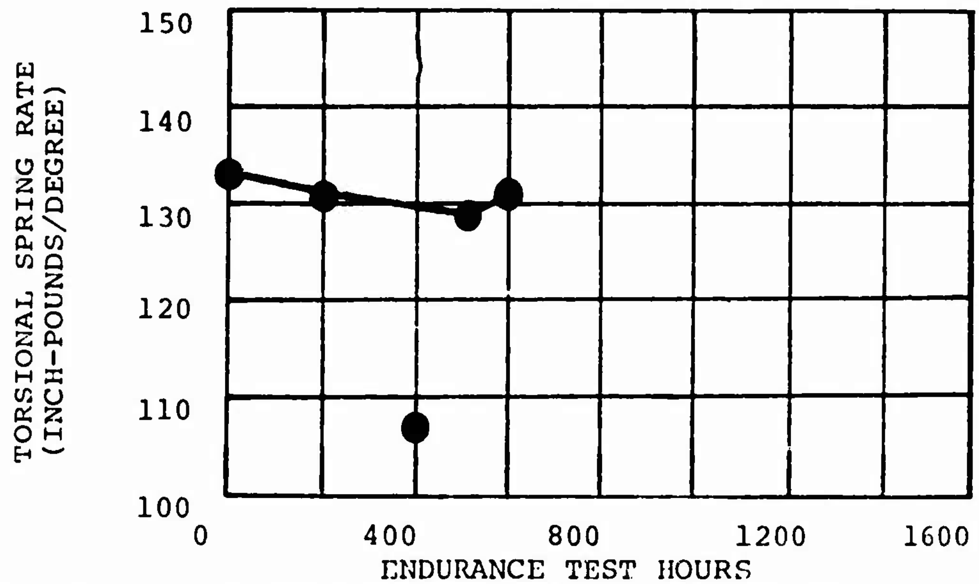


Figure 30. Static Axial Spring Rate of Test Sample 2 (S/N 002).



Note: Tests performed without axial load applied.

Figure 31. Static Torsional Spring Rate of Test Sample 3 (S/N 004).

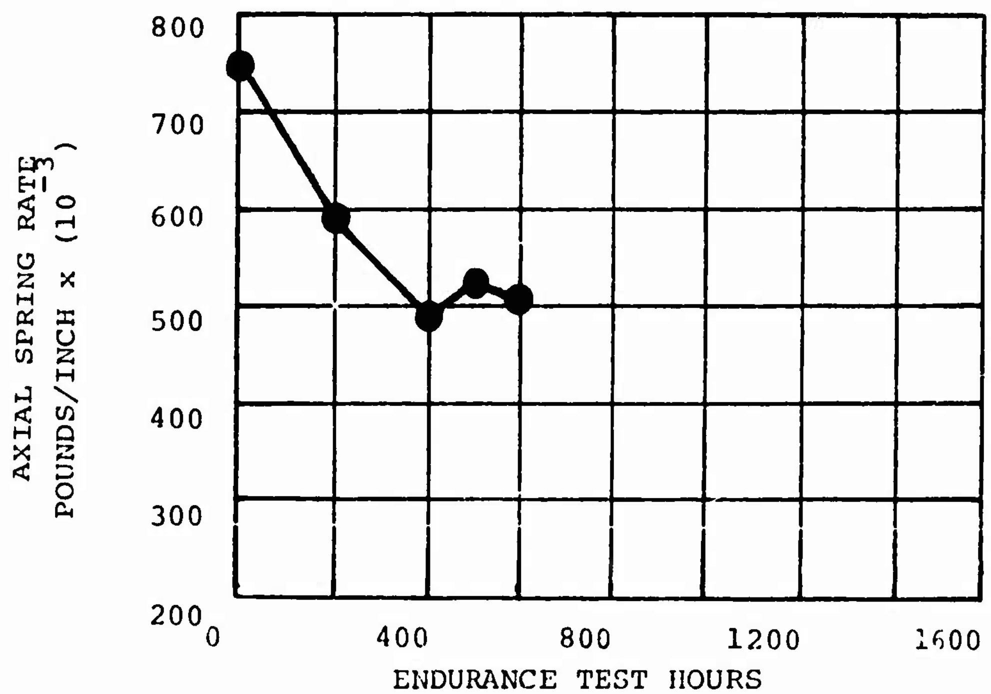
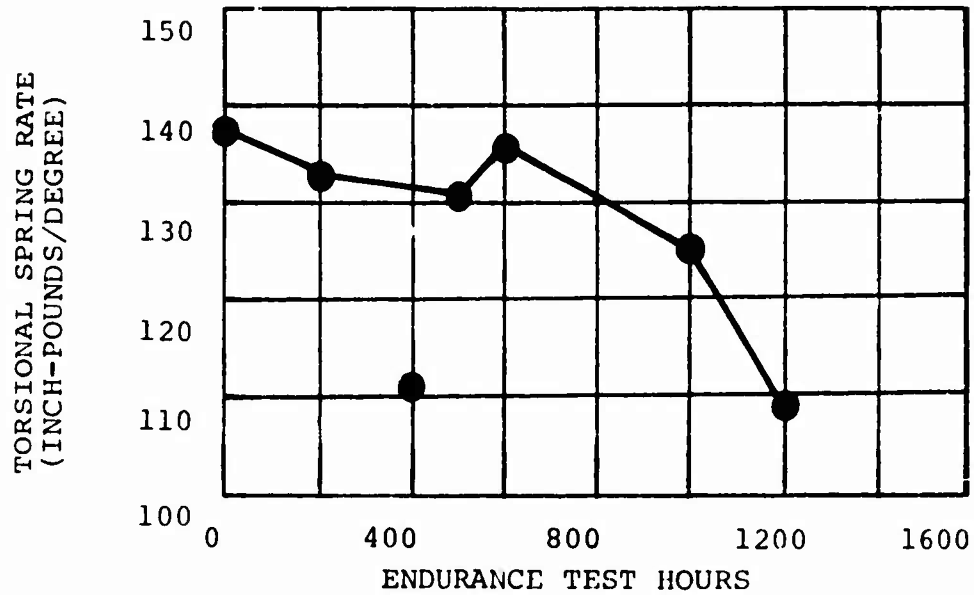


Figure 32. Static Axial Spring Rate of Test Sample 3 (S/N 004).



Note: Tests performed without axial load applied.

Figure 33. Static Torsional Spring Rate of Test Sample 4 (S/N 005).

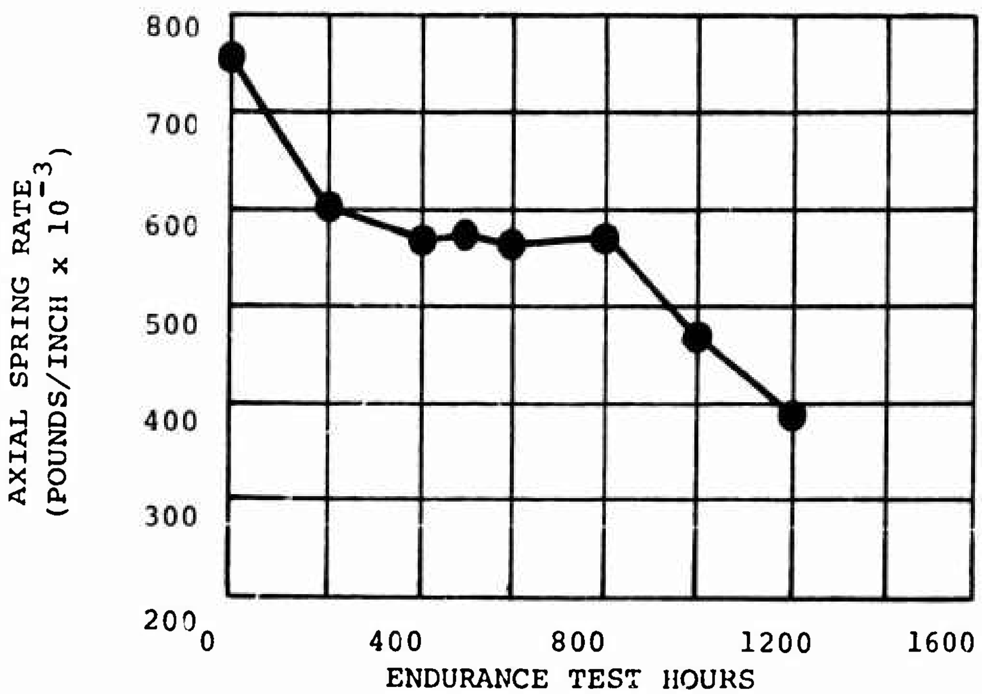
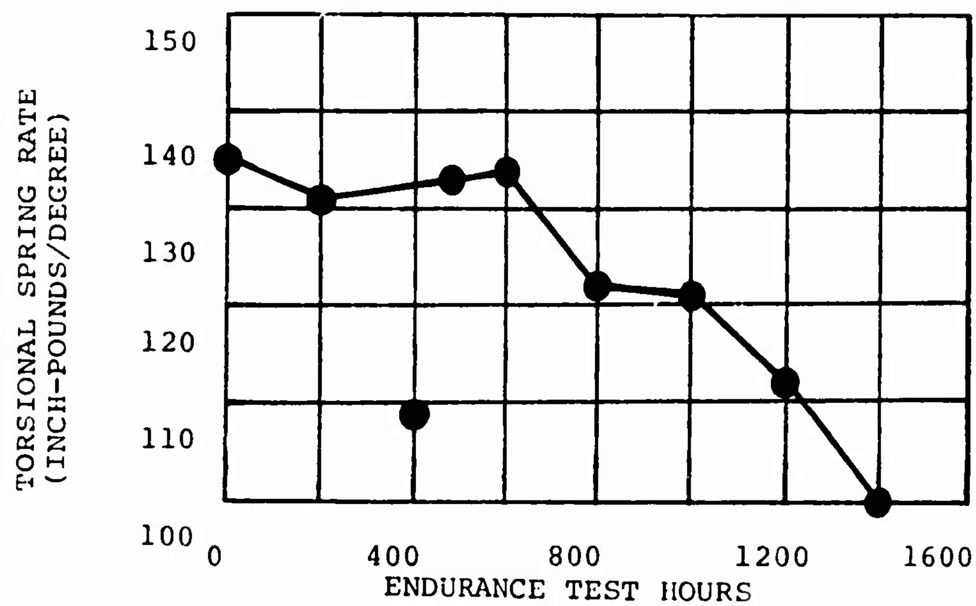


Figure 34. Static Axial Spring Rate of Test Sample 4 (S/N 005).



Note: Tests performed without axial load applied.

Figure 35. Static Torsional Spring Rate of Test Sample 5 (S/N 006).

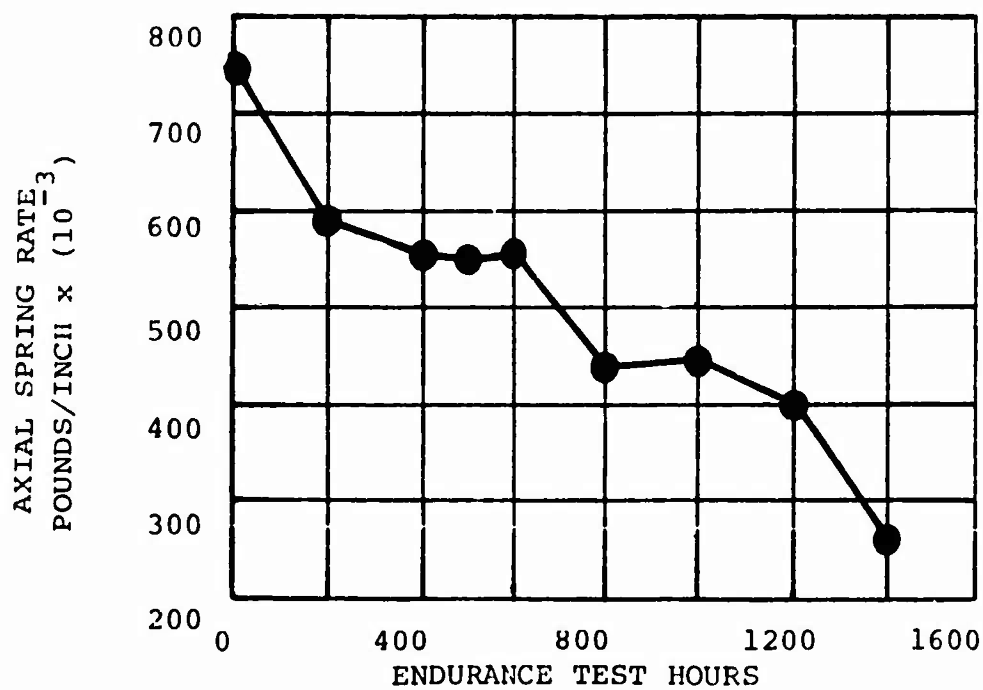
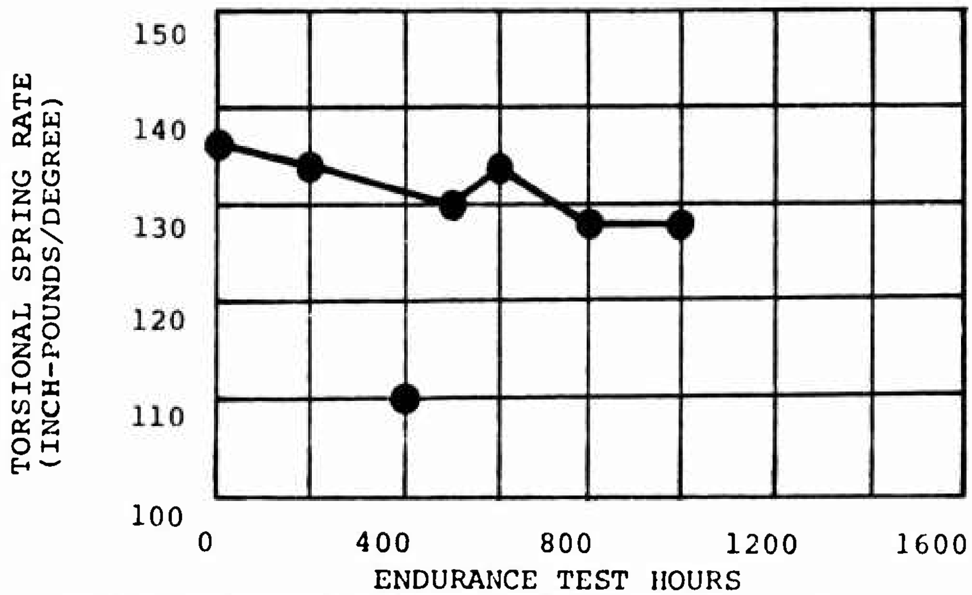


Figure 36. Static Axial Spring Rate of Test Sample 5 (S/N 006).



Note: Tests performed without axial load applied.

Figure 37. Static Torsional Spring Rate of Test Sample 6 (S/N 007).

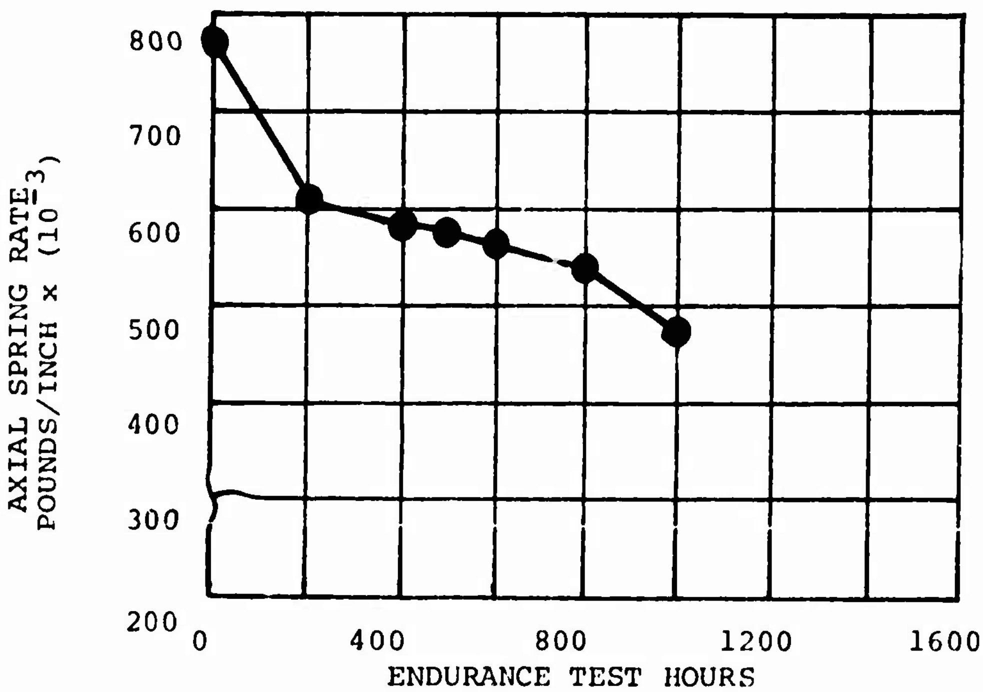
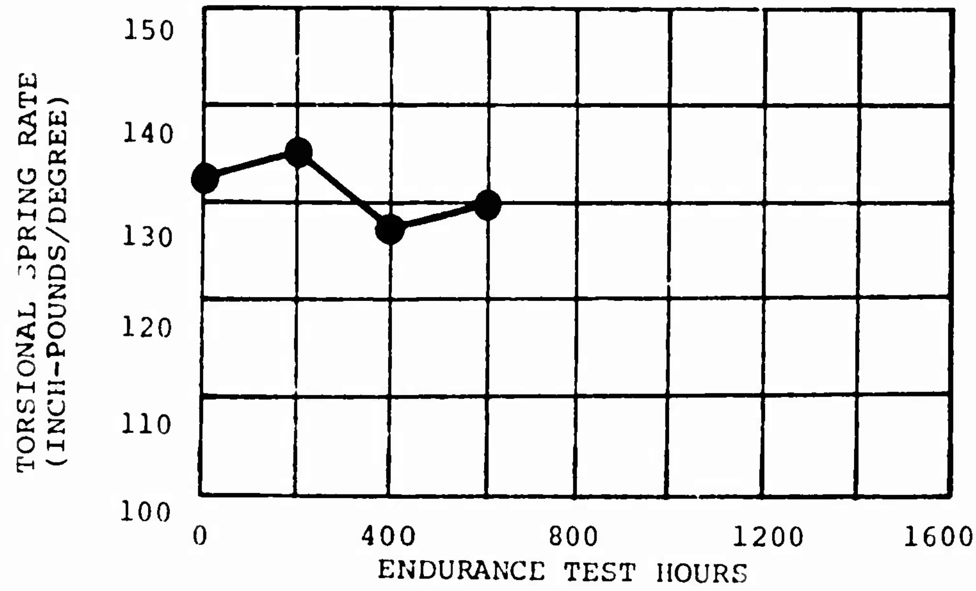


Figure 38. Static Axial Spring Rate of Test Sample 6 (S/N 007).



Note: Tests performed without axial load applied.

Figure 39. Static Torsional Spring Rate of Test Sample 14 (S/N 013).

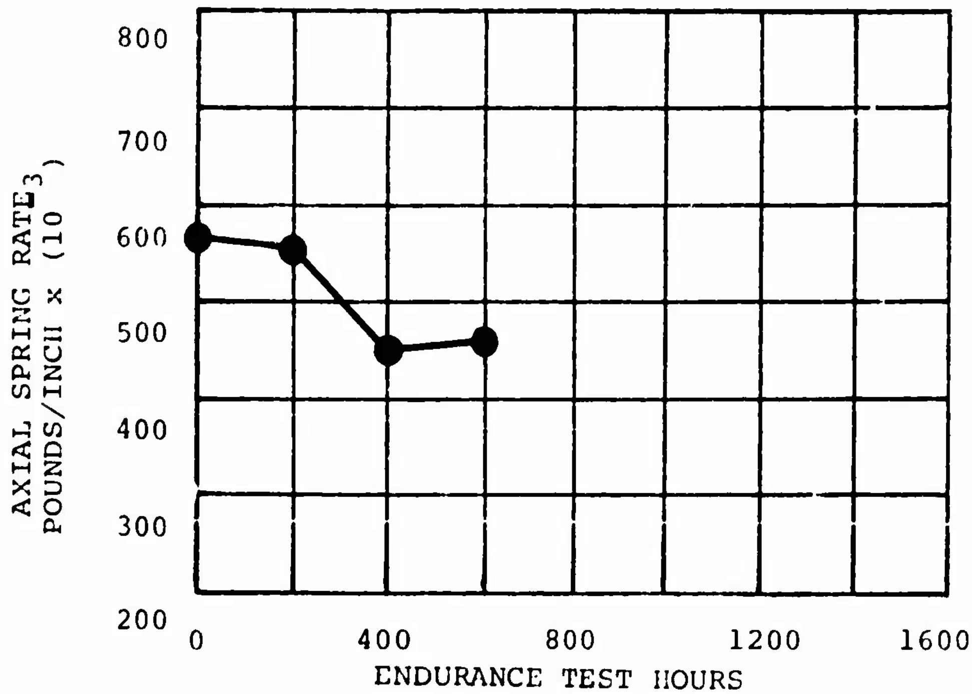
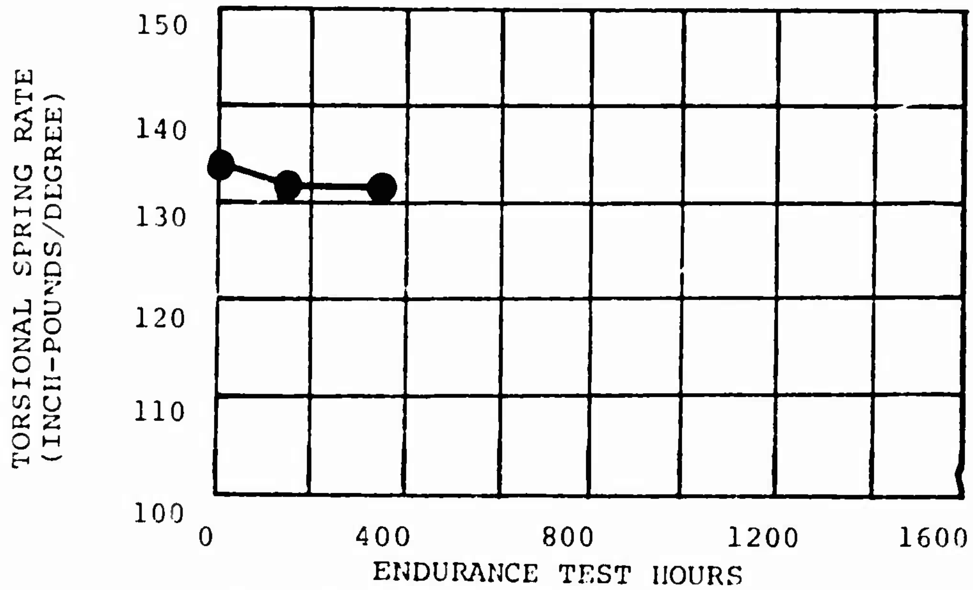


Figure 40. Static Axial Spring Rate of Test Sample 14 (S/N 013).



Note: Tests performed without axial load applied.

Figure 41. Static Torsional Spring Rate of Test Sample 15 (S/N 015).

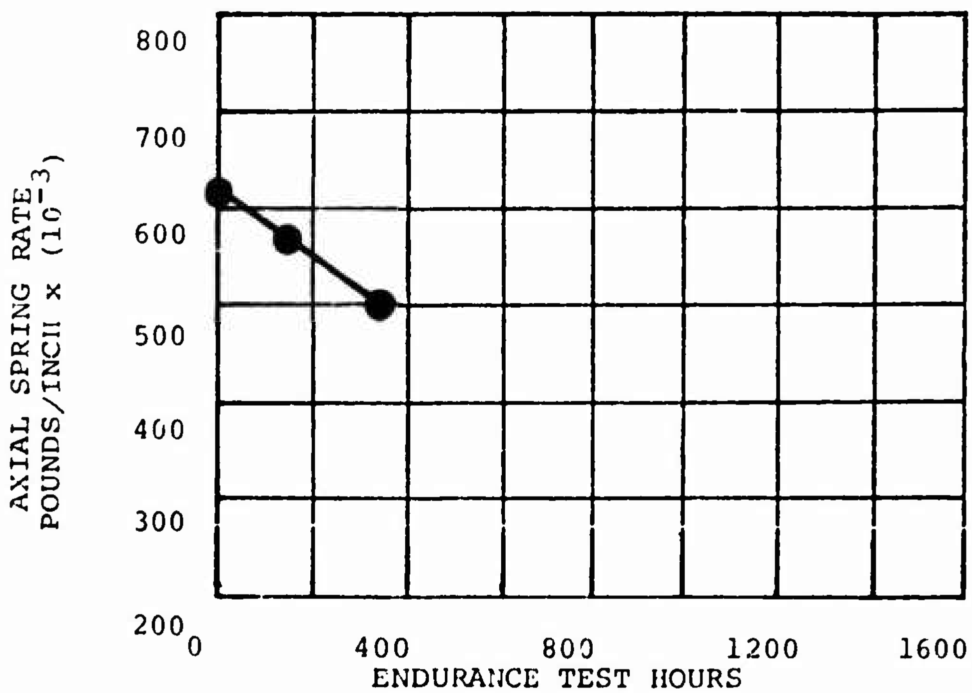
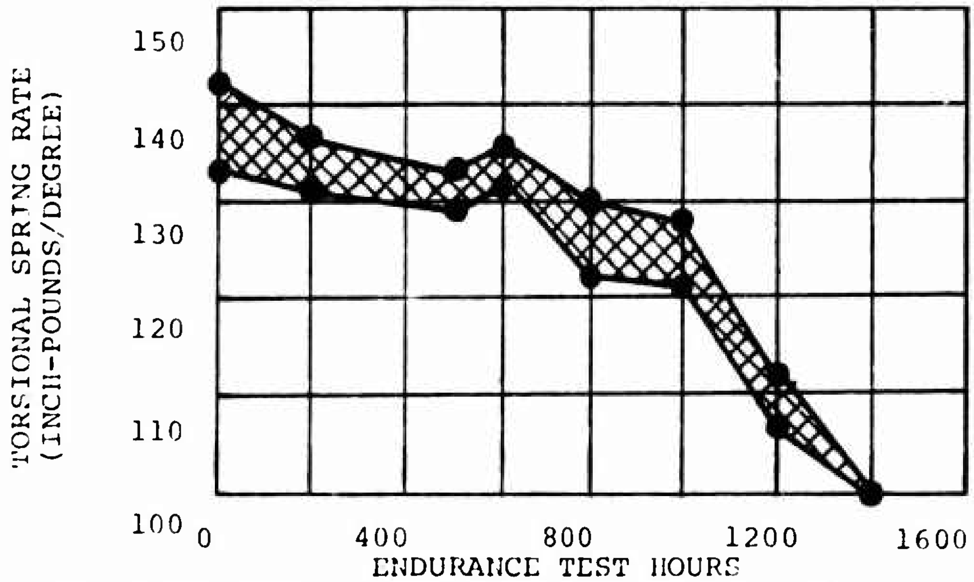


Figure 42. Static Axial Spring Rate of Test Sample 15 (S/N 015).



Note: Tests performed without axial load applied.

Figure 43. Static Torsional Spring Rate Envelope of Test Samples 1 through 6.

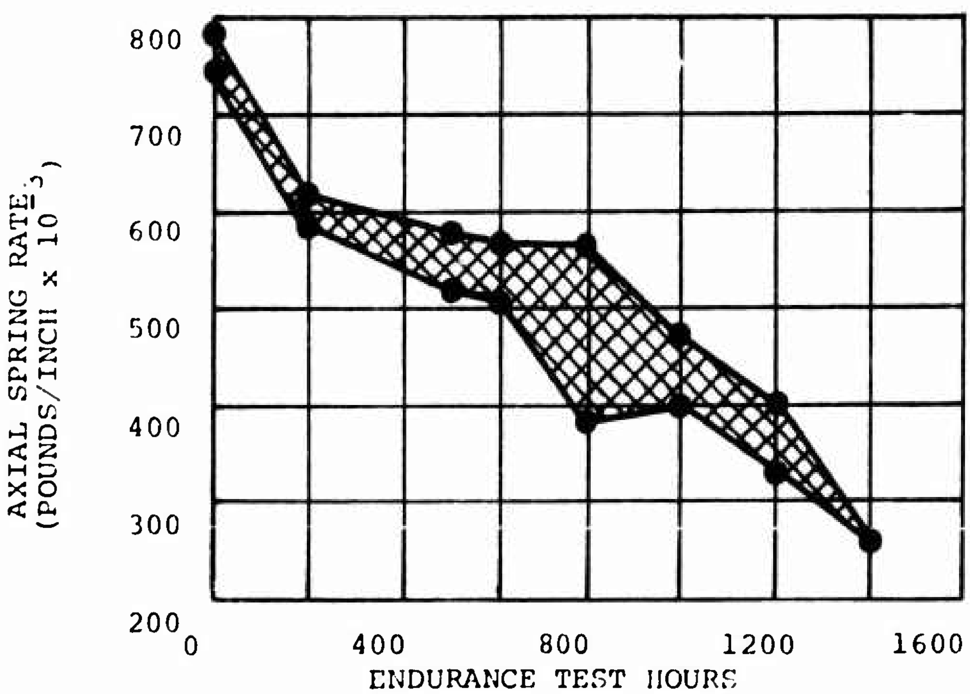


Figure 44. Static Axial Spring Rate Envelope of Test Samples 1 through 6.

TABLE VII. STATIC TORSIONAL SPRING RATE OF SAMPLE PAIRS

Endurance Test Hours	Static Torsional Spring Rate (inch-pounds/degree)		
	Test Samples 1 and 2	Test Samples 3 and 4	Test Samples 5 and 6
0	280	256	284
200	236	261	215
400	282	275	262
500	283	264	285
600	290	297	281
800	292	---	292
1000	337	---	324

<u>Note</u>: Test performed with a 56,000-pound axial load applied to bearings.

TABLE VIII. DYNAMIC TORSIONAL SPRING RATE OF SAMPLE PAIRS

Endurance Test Hours	Dynamic Torsional Spring Rate (inch-pounds/degree)		
	Test Samples 1 and 2	Test Samples 3 and 4	Test Samples 5 and 6
0	318	308	300
200	291	284	276
400	290	312	298
500	317	334	320
600	350	345	291
800	350		337
1000	484		368

<u>Note</u>: Test performed with a 56,000-pound axial load applied to bearings.

PERIODIC STATIC AND DYNAMIC RADIAL SPRING RATE TESTING

Table IX contains the static and dynamic radial spring rate data obtained on the endurance test samples. This test was performed while the samples were installed in the test machine with the normal centrifugal force applied. The radial load was applied with the hydraulic actuators used in the endurance tests,and the deflections were measured with dial indicators.

Because of the relatively high spring rate in the radial direction, the deflections obtained are small and the measurements difficult. In addition, fixture rigidity becomes extremely important. A number of inconsistencies are evident in examining the test data. Variation from sample to sample, particularly when they were new, was much greater than expected. In addition, the dynamic spring rate is in many cases lower than the static, which is inconsistent with past experience. This data is felt to be of questionable accuracy and of little value in monitoring bearing condition.

DIMENSIONAL INSPECTIONS OF METAL PARTS

Three of the dimensions inspected during the periodic tests were directly related to wearing of the outer major metal component. The .7505/.7495 attachment hole diameter was inspected at four places on each sample during the periodic inspection. Table X lists the average amount of change from the original hole diameter at the "zero" hour periodic. In general, the diameter changed very little from the 200-hour inspection until bearing removal. However, in several cases, a relatively large increase in the diameter occurred during the initial 200 hours of testing. This is attributed to the wearing away of excess cadmium plating at the edge of the hole which probably occurred during the first 200 hours.

Table XI contains the average change in the 1.393/1.391 inch width between the attachment lugs. A positive value indicates an increase in slot width and a negative value indicates a width decrease. The change was slight, possibly attributed to a wearing away of the plating. A decrease in width cannot be explained and is most likely an error in inspection. The flatness of the attachment lug surface was inspected and in all cases, was less than .001 inch.

An attempt was made to duplicate the attachment configuration used in the rotor installation. This was not achieved fully because of test machine requirements and cost restrictions. Therefore, the above housing dimensional data should be used with caution.

TABLE IX. STATIC AND DYNAMIC RADIAL SPRING RATES OF TEST SAMPLE PAIRS

Endurance Test Hours	Static Radial Spring Rate (pounds/inch x 10^{-6}) Test Sample Number 1	2	3	4	5	6
0	2.0	2.0	1.7	1.85	1.85	2.0
200	1.7	1.5	1.5	1.3	1.3	1.3
400	1.7	1.0	.92	.86	.92	.80
500	.8	1.0	1.2	1.0	2.4	1.5
600	1.1	1.5	1.7	2.0	2.4	2.0
800	1.2	1.5	-	1.2	2.0	1.1
1000	1.3	1.7	-	2.0	1.3	1.7
1200	-	1.5	-	1.6	2.4	-

Endurance Test Hours	Dynamic Radial Spring Rate (pounds/inch x 10^{-6}) Test Sample Number 1	2	3	4	5	6
0	1.35	1.6	1.6	1.35	2.8	1.45
200	1.3	1.1	1.2	1.1	1.3	1.3
400	1.0	.73	.73	.73	.73	1.0
500	2.3	1.1	2.3	2.0	1.1	1.1
600	1.3	1.2	1.45	1.3	1.8	2.0
800	1.7	1.2	-	1.4	.94	1.3
1000	1.0	1.2	-	1.1	1.2	1.1
1200	-	1.6	-	1.1	1.3	-

TABLE X. DIMENSIONAL INSPECTION OF .7505/.7495 DIAMETER HOLES

Endurance Test Hours	Average Change in Four .7505/.7495 Diameter Holes (in.)					
	Test Sample Number					
	1	2	3	4	5	6
0						
200	.0007	.0002	.0010	.0010	.0001	.0000
400	.0009	.0010	.0010	.0008	.0001	.0001
500	.0009	.0011	.0011	.0009	.0002	.0002
600	.0011	.0011	.0011	.0009	.0003	.0002
800	.0011	.0012	-	.0009	.0003	.0002
1000	.0011	.0012	-	.0010	.0003	.0002
1200	-	.0013	-	.0011	-	-

TABLE XI. DIMENSIONAL INSPECTION OF 1.393/1.391 INCH SLOT WIDTH

Endurance Test Hours	Average Change in 1.393/1.391 Inch Dimension (in.)					
	Test Sample Number					
	1	2	3	4	5	6
0						
200	+.001	.001	-.001	.001	.001	.001
400	-.001	.002	.002	.000	.002	.002
500	-.001	.002	.002	.001	.001	.002
600	-.003	-.002	.002	.001	.001	.002
800	-.002	.002	-	.001	.001	.002
1000	-.002	.002	-	.001	.001	.001
1200	-	.000	-	.000	.002	-
1400	-	-	-	-	.002	-

DIMENSIONAL INSPECTION OF THE FLEXING ELEMENT

Several of the dimensions inspected during the periodic tests spanned the elastomer and shim flexing element. As a result, a significant change in these dimensions was expected due to fatigue of the samples. The free height of the samples was measured to determine the amount of axial deflection which was permanent. This measurement is called "permanent set" and is common in elastomeric components.

Figure 45 contains the envelope within which the amount of permanent set of all the bearings occurred. A portion of this permanent set is due to the loss of elastomer due to abrasion which continues to increase as the bearing fatigues. A separate portion is due to an internal restructuring of the elastomer which occurs with high steady loads such as the centrifugal force. This type of set increases quickly during the early part of a bearing life and levels off to a slow gradual increase thereafter. The data available is not sufficient for determining the relative amounts of these two phenomena occurring in Figure 45.

The dimensional data obtained on torsional set of the samples as well as parallelism and concentricity of the inner and outer attachment components did not indicate any consistent trends. It was found to be of little value in monitoring the condition of the test samples.

VISUAL INSPECTION

All bearings were inspected visually and photographed during the periodic inspections. In addition, significant occurrences during the endurance test were noted. Detailed inspection of the samples while installed in the endurance test machine was difficult because of the fixture design.

Tables XII through XVII contain the visual inspection records of the test samples. Examination of the records indicates that all test samples were abrading elastomer prior to the 200-hour periodic inspection. Test samples 1 and 2 were the first bearings to begin abrading elastomer. This occurred approximately 139 hours into the endurance test. By 185 hours, all test samples were abrading

The first abrasion on all samples occurred in the innermost sections directly in line with the radial load. The radial load was applied in the blade chordwise direction in line with the outer housing attachment lugs. The portion of the bearing placed in compression by the radial load was the first to show evidence of failure. This was followed by abrasion on the tension side of the bearing. The elastomer abrasion progressed from the innermost sections outward and from the area in line with the radial load to the entire circumference.

All samples degraded at approximately the same rate, making it difficult to rank the samples with respect to degree of deterioration. In addition to the abrasion of elastomer similar to an eraser crumbling, a creasing of the elastomer due to the repeated centrifugal force application was noted. These crease marks were not considered detrimental. They were indications of the elastomer flexing.

Visual inspection of the metal parts revealed slight nicks in the major metal components as well as the shims. These nicks resulted from insufficient care during sample removal and replacement during the periodic testing. Some of the shim failures during later phases of the test may have been initiated by this damage, although this could not be proven.

The initial deterioration of the samples was in the form of fine hair-like particles. During the progress of the test, this became more severe until in some instances, larger particles were extruded from the sections. The loss of elastomer in some sections resulted in a lack of shim support leading to shim bending and fretting. This led to shim fracture which in turn resulted in increased abrasion.

FAILURE SUMMARY

Test sample 3 failed at 800 hours during the manual condition of $\pm$ 12° pitch input. The loss of elastomer in the first section resulted in a decrease in the shear load area. The bearing was unable to withstand the 12° input, and the first section failed in shear. A complete separation of the inner member from the bearing occurred. Inspection of the failed area revealed a good bond.

Test samples 4 and 6 were removed from test at the first evidence of shim failure. This occurred after 1310.4 hours

of testing on test sample 4 and 1065.3 hours on test sample 6. The abrasion of elastomer and the inaccessibility of the test samples when installed in the test machine made the detection of shim failure difficult.

Both test samples 1 and 2 were removed from test because of heat buildup resulting from internal friction. Although temperatures were not measured, they were of sufficient magnitude to cause rapid elastomer degradation. Test sample 1 was removed at 1133.95 hours and test sample 2 at 1319.2 hours.

Test sample 5 remained on test until the 1400-hour level. The sample appearance as well as the decrease in axial spring rate dictated removal. Closer inspection revealed a cracked shim.

In all cases, the bearings were able to support the radial and axial loads and accommodate the torsional motion until their removal from test. No failures of the inner and outer attachment metal parts occurred.

RELIABILITY ANALYSIS

A common statistical technique used in the analysis of test data is the Weibull analysis. This method is frequently used in the ball and roller bearing industry to estimate the frequency distribution of fatigue failures. The percentage of bearings which will fail in a given time can be predicted. The time by which ten percent of the bearings will have failed is referred to as the B-10 life.

The number of test samples available for analysis affects the accuracy of the analysis. The greater the number of samples, the greater the accuracy of the predictions which result. All test samples should be subjected to identical test conditions for the analysis to be valid. In the LM-726-1 test program, six samples were endurance tested with each of three pairs exposed to a different environment. In order to apply the Weibull analysis to the LM-726-1, we must conclude that the different environmental exposure did not affect fatigue life. This conclusion seems valid based on examination of the periodic spring rate data.

A detailed discussion of the Weibull analysis technique is beyond the scope of this report. The results of the analysis will be presented with a brief discussion of the implications.

Figure 46 is a plot of the six failure points on Weibull graph paper. The location of each sample point on the abscissa is the number of hours at which failure occurred. The location along the ordinate is the median rank of each failure point as determined from a table of median ranks for a sample size of six. Table XVIII contains the failure points with their corresponding median ranks.

Confidence intervals representing a 90% confidence level have been plotted in Figure 46. The intersection of the best straight line through the failure points with the 10 percent level is the B-10 life. The B-10 life for the LM-726-1 is 812 hours based on the analysis of six failures. The 90% confidence limits on the B-10 life are approximately 475 hours to 1100 hours. We can therefore state with 90% confidence that 10% of the bearings will fail within this interval.

We can also examine a particular life value, such as 1200 hours, by drawing a vertical line at that level intersecting the Weibull line and the confidence intervals. The intersection of the Weibull line occurs at 50%, indicating that 50% of the bearings will have failed at 1200 hours. Applying 90% confidence intervals, as few as 22% and as many as 82% will have failed at 1200 hours. The wide margin indicates a large degree of uncertainty in predicting life characteristics. This is a direct result of the small sample size. With a larger sample size, the 90% confidence intervals will "close in" around the Weibull line. As a result, the upper and lower 90% confidence levels will be closer.

PHOTOGRAPHS

The progression of failure of test sample 5 is shown in Figures 47 through 58. The appearance of this sample was typical of all samples tested. A slight amount of elastomer abrasion is visible in the innermost sections of the bearing in Figure 48. The gummy appearance of the elastomer in Figures 49 and 50 is a result of accidental exposure to test machine oil. The abrasion is quite heavy at the 800-hour level shown in Figure 52. All elastomer sections are abrading elastomer at the 1200-hour level as shown in Figures 55 and 56. Voids are visible in several sections of the failed bearing at 1400 hours, and several large pieces of elastomer have extruded from the small end of the sample.

The "hair-like" abrasion typical of the early failure stages is shown in Figure 59. This is a view of test sample 2 looking at 90 degrees to the radial load. Test sample 3 is shown in the sand and dust chamber in Figure 60. Its appearance when cleaned was similar to the remaining samples.

Test sample 3 after failure at 800 hours is shown in Figure 61. Failure was a shearing of the elastomer in section one resulting in a complete separation of the inner member. At this point in the endurance test, deterioration was primarily in the inner six sections. A sectioned view of test sample 6, in Figure 62, illustrates the elastomer sections voids and the cracked shim. Figure 63 clearly illustrates the voids in sections one and five.

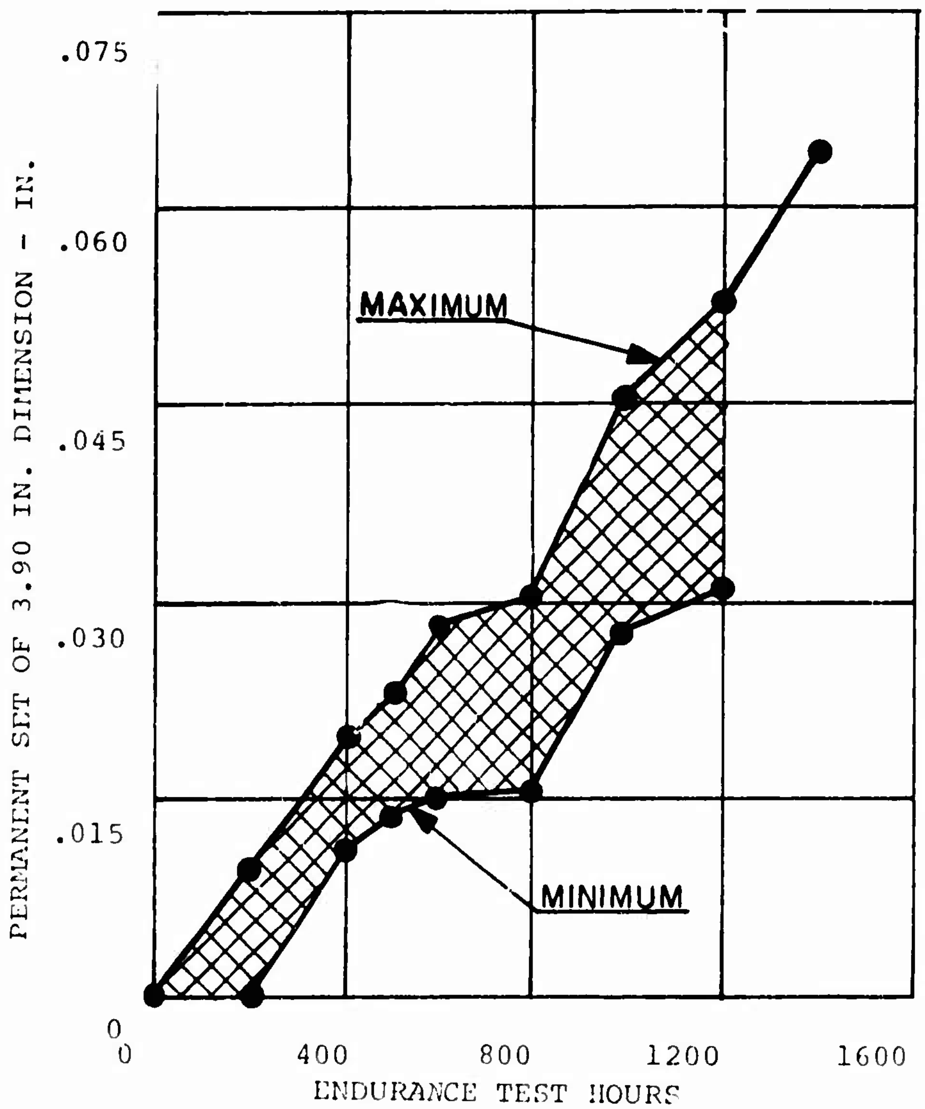


Figure 45. Permanent Set Envelope of Endurance Test Samples.

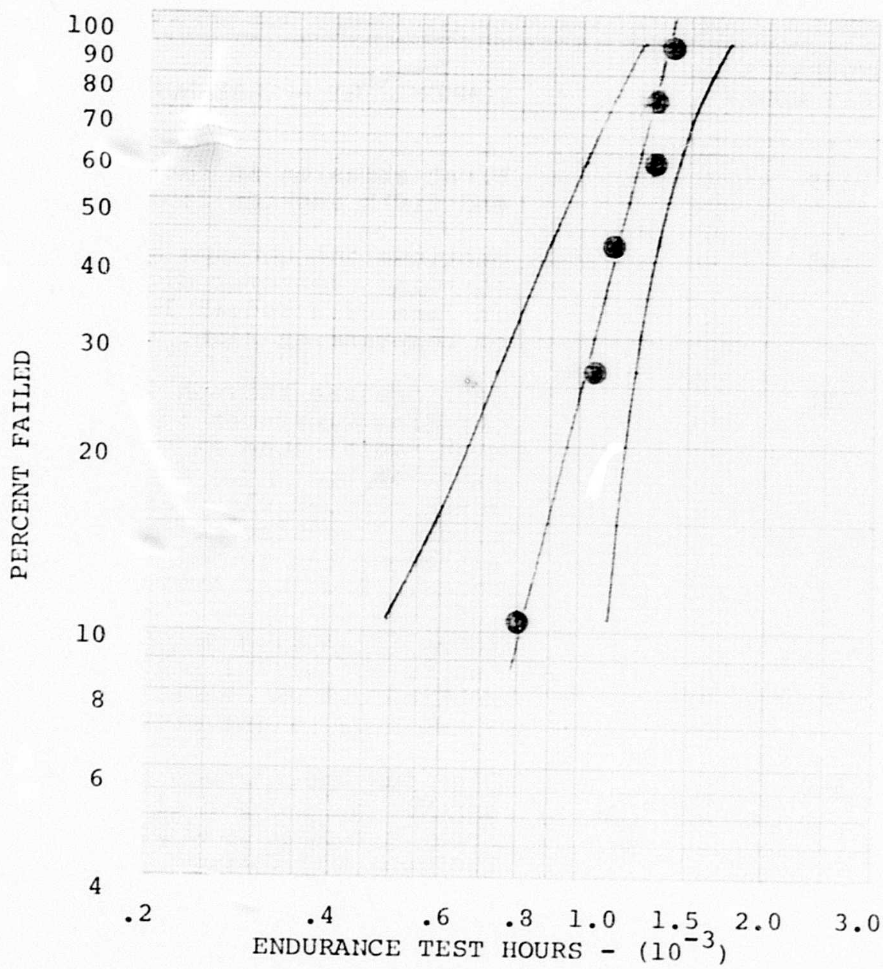


Figure 46. Weibull Plot of LM-726-1 Failures With 90 Percent Confidence Limits.

TABLE XII. VISUAL INSPECTION RECORD OF TEST SAMPLE 1

ENDURANCE TEST HOURS	COMMENTS ON APPEARANCE
139	First abrasion in fourth and fifth section from inside.
185	Sections one through six abrading elastomer directly in line with radial load on compression side.
400	Sections one through six abrading elastomer in line with radial load on both sides of bearing. Sections seven through eleven show slight "creasing" of elastomer due to bulge over shims. Sections twelve and thirteen no damage. Elastomer is swollen slightly due to accidental test machine oil exposure. Shims have slight nicks.
500	Sections one through three abraded to a depth of .70 inch in radial load path. Sections one through nine abraded, but no appreciable depth.
600	Depth measurements. Section one .85 inch deep on tension side and .70 inch deep on compression side. Section three is .85 inch deep on compression side. Section five is .60 inch deep on tension side.

TABLE XII. CONTINUED	
ENDURANCE TEST HOURS	COMMENTS ON APPEARANCE
859	Large pieces of elastomer are beginning to extrude from compression and tension sides.
978	First evidence of adjacent shims touching and fretting.
1000	Depth measurements. Section one 1.3 inches to 2.2 inches on tension side and 1.1 inches compression side. Section three is 1.9 inches deep on compression side. Section five is 1.8 inches deep on compression side.
1133.95	Failure - Excessive elastomer extrusion resulting in internal friction and excessive heat buildup.

TABLE XIII. VISUAL INSPECTION RECORD OF TEST SAMPLE 2	
ENDURANCE TEST HOURS	COMMENTS ON APPEARANCE
139	First abrasion in first and third sections from inside.
185	Sections one through four abrading elastomer directly in line with radial load on compression side.
400	Sections one through three show worst abrasion. Section one is .20 inch deep in one location. Sections four through six show slight abrasion. Sections seven through ten show slight creasing. Sections eleven through thirteen show no damage. Shims have slight nicks.
500	Sample not available for inspection.
600	Depth measurements: Section one is .40, 1.0, and .90 inches deep at three locations on compression side. Section three is .80 inch deep on compression side.
839	First evidence of metal fretting between first shim and inner member.

TABLE XIII. CONTINUED

ENDURANCE TEST HOURS	COMMENTS ON APPEARANCE
1000	Depth measurements: Section one is 1.4 inches to 1.5 inches deep at three locations on compression side. Section three is 1.8 inches deep on compression side.
1319.2	Failure -- Excessive elastomer extrusion resulting in internal friction and excessive heat buildup. A closer inspection revealed a 95 percent loss of elastomer in Section one.

TABLE XIV. VISUAL INSPECTION RECORD OF TEST SAMPLE 3	
ENDURANCE TEST HOURS	COMMENTS ON APPEARANCE
139	No abrasion noted.
169	Abrasion noted in Sections two and five.
400	Sections one through three show heavy abrasion around entire circumference. Sections four through six slightly abraded in radial load path. Sections seven through nine - slight creasing. Sections ten through thirteen - no deterioration. Shims have slight nicks.
500	Section one abraded to .70 inch deep in radial load path. Sections one through nine abraded, but no appreciable depth.
600	Section one is .20, .80, and .40 inch deep at three locations on compression side. Section three is .40 inch deep on compression side.
800	Failure - A complete separation occurred in the first elastomer layer between the inner member and the first shim. This occurred during the 265th cycle of the first manual condition of $\pm$ 12 degrees pitch input.

TABLE XV. VISUAL INSPECTION RECORD OF TEST SAMPLE 4

ENDURANCE TEST HOURS	COMMENTS ON APPEARANCE
139	No abrasion noted.
185	Sections one through six abrading elastomer directly in line with radial load on compression side.
400	Sections one, three, and five show slight abrasion in radial load path. Sections two, four, and six through nine show very slight creasing. Sections ten through thirteen no deterioration. Shims have slight nicks.
500	Section one abraded to .30 inch depth. Section three abraded to .60 inch depth. Sections one through five abraded, but no depth.
600	Section one abraded to .40 inch depth on compression side. Section three is .60 inch deep on compression side.
682	Swelling of elastomer noted due to reactant exposure. (Either JP-4 or Varsol)
958	First evidence of fretting between fourth and fifth shims on compression side.

TABLE XV. CONTINUED

ENDURANCE TEST HOURS	COMMENTS ON APPEARANCE
1000	Depth measurements. Section one is .80 inch deep on compression side. Section three is 1.8 inches deep on compression side and 1.0 inches deep on tension side. Section five is 1.5 inches deep on compression side and 1.1 inches deep on tension side.
1310.4	Failure - Two shims fractured on the compression side of the radial load path. One piece (.75 inch of circumference) of the second shim and one piece (1.25 inches of circumference) of the fourth shim fractured.

TABLE XVI. VISUAL INSPECTION RECORD OF TEST SAMPLE 5

ENDURANCE TEST HOURS	COMMENTS ON APPEARANCE
139	No abrasion noted.
185	Sections one through five abrading elastomer directly in line with radial load on compression side.
400	Sections one through six show abrasion. Elastomer is swollen and gummy due to accidental exposure to test machine oil. Sections seven through eleven show evidence of creasing. Shims have slight nicks.
500	Section one abraded to .70 inch deep in radial load path. Section three abraded to .40 inch deep. Sections one through nine abraded, but no depth.
600	Section one is .40 inch and .80 inch deep at two locations on compression side.
958	First evidence of fretting on compression side.
1000	Depth measurements. Section one is 2.3 inches deep on compression side. Section three is 1.3 inches deep on compression side. Section four is 1.1 inches deep on compression side.

TABLE XVI. CONTINUED	
ENDURANCE TEST HOURS	COMMENTS ON APPEARANCE
1400	Failure - The static axial spring rate decreased 65 percent. Excessive extrusion occurred and close inspection revealed a crack in the fourth shim.

TABLE XVII. VISUAL INSPECTION RECORD OF TEST SAMPLE 6

ENDURANCE TEST HOURS	COMMENTS ON APPEARANCE
139	No abrasion noted.
185	Sections one through nine abrading elastomer directly in line with radial load on compression side.
400	Sections one through five show heavy abrasion. Sections six through nine show slight creasing of elastomer. Sections ten through thirteen show no evidence of deterioration. Some evidence of slight oil exposure from test machine.
500	Section three abraded to .70 inch deep in radial load path. Section five abraded to .50 inch deep. Sections one through nine abraded, but no appreciable depth.
600	Section one is .20 inch and .30 inch at two locations. Section three is .70 inch deep on tension side and .95 inch deep on compression side.
958	First evidence of fretting on both compression and tension sides.

TABLE XVII. CONTINUED

ENDURANCE TEST HOURS	COMMENTS ON APPEARANCE
1000	Section one is .80 inch deep on tension side. Section three is 1.0 inch deep on tension side and 1.8 inches deep on compression side. Section five is 1.5 inches deep on compression side.
1065.3	Failure - A triangular piece of the second shim fractured and separated. Closer examination revealed a crack in the third shim. Both failures occurred on the compression side.

TABLE XVIII. WEIBULL ANALYSIS DATA

Sample Number	Rank Order	Hours to Failure	Median Rank	90 Percent Confidence Intervals (Hours) Lower	Upper
3	1	800	10.9	491	1108
6	2	1065	26.4	736	1238
1	3	1134	42.1	890	1342
4	4	1310	57.8	1012	1443
2	5	1319	73.5	1126	1561
5	6	1400	89.0	1255	1739

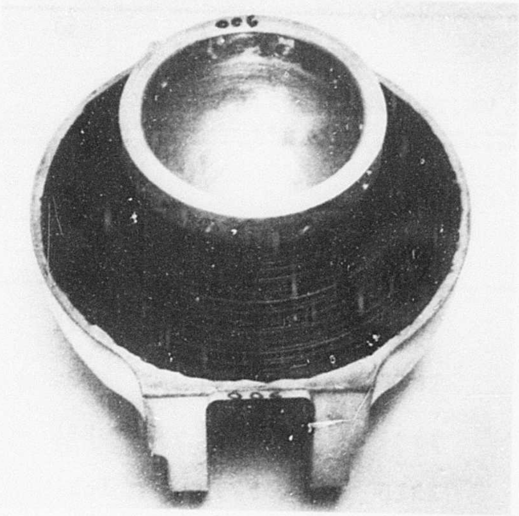


Figure 47. Test Sample 5 (S/N 006) at Zero Hours.

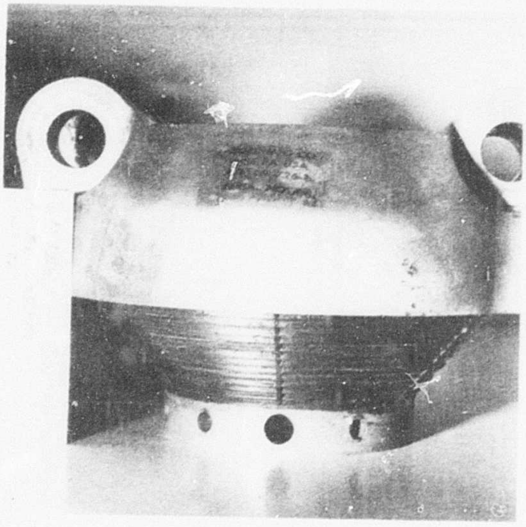


Figure 48. Test Sample 5 (S/N 006) at 200 Hours.

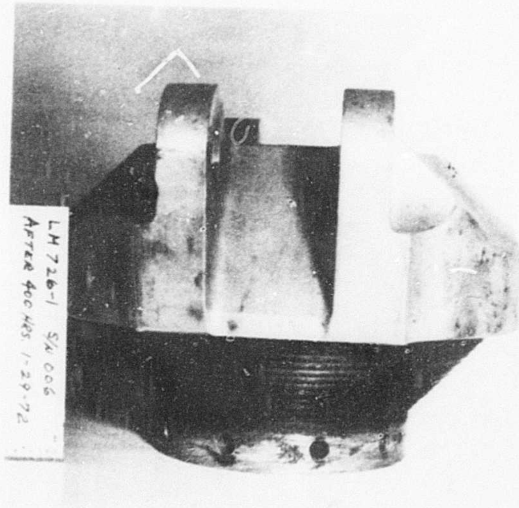


Figure 49. Test Sample 5 (S/N 006) at 400 Hours.

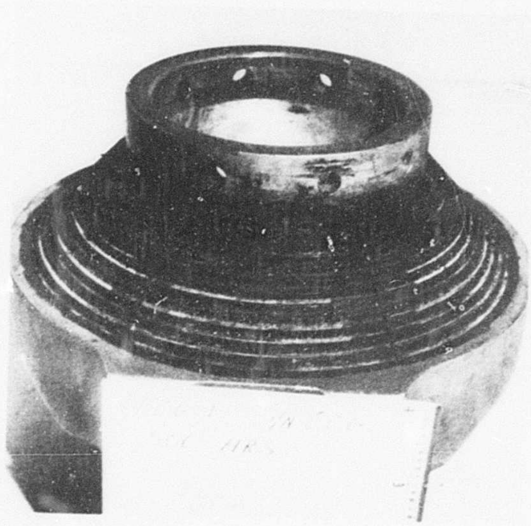


Figure 50. Test Sample 5 (S/N 006) at 500 Hours.

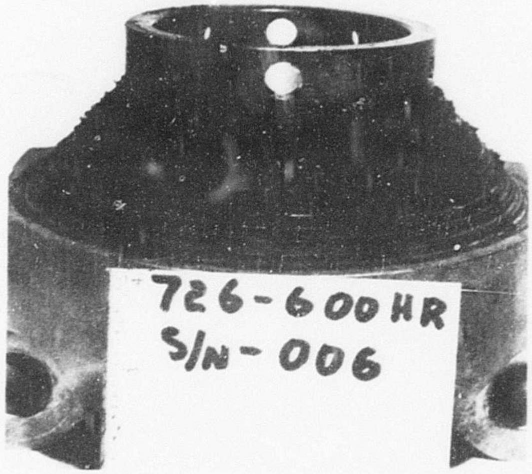


Figure 51. Test Sample 5
(S/N 006) at 600
Hours.

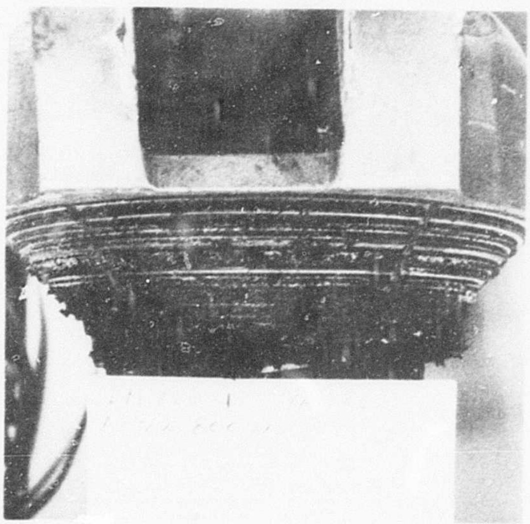


Figure 52. Test Sample 5
(S/N 006) at 800
Hours.

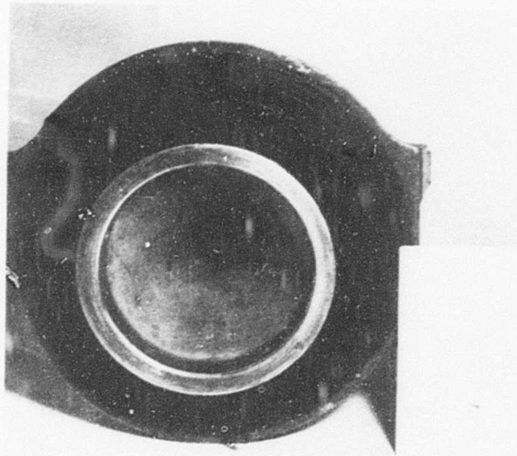


Figure 53. Inboard View of Test Sample 5 (S/N 006) at 1,000 Hours.

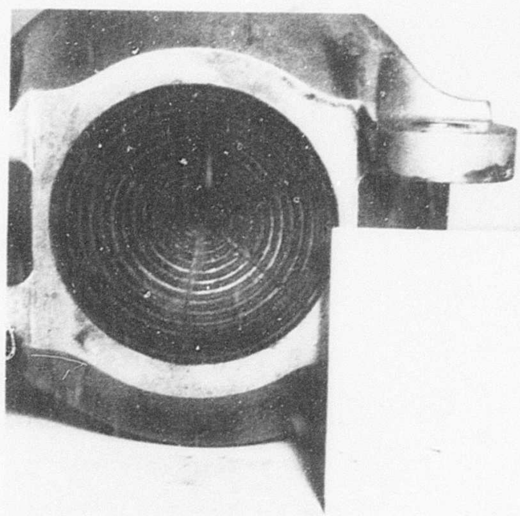


Figure 54. Outboard View of Test Sample 5 (S/N 006) at 1,000 Hours.

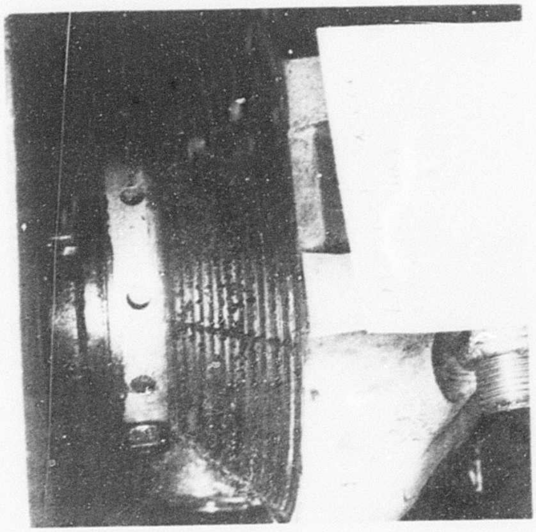


Figure 55. Test Sample 5 (S/N 006) at 1200 Hours.

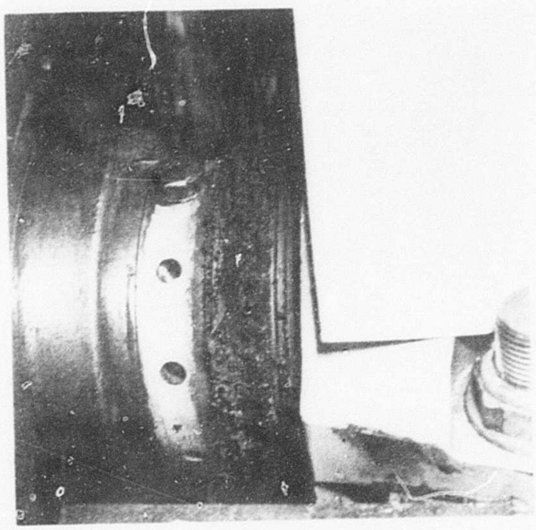


Figure 56. Test Sample 5 (S/N 006) at 1200 Hours, Rotated 90 Degrees.

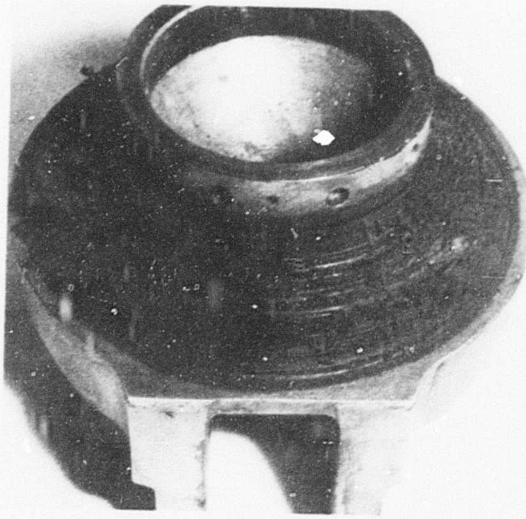


Figure 57. Inboard View of Test Sample 5 (S/N 006) at 1400 Hours.

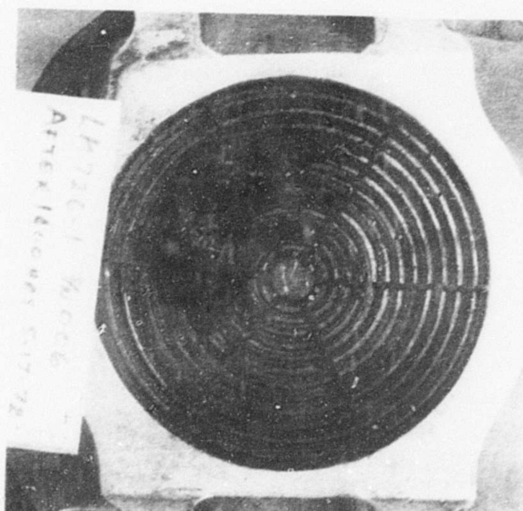


Figure 58. Outboard View of Test Sample 5 (S/N 006) at 1400 Hours.

Figure 59. Abrasion of Test
Sample 2 (S/N 002)
at 800 Hours.

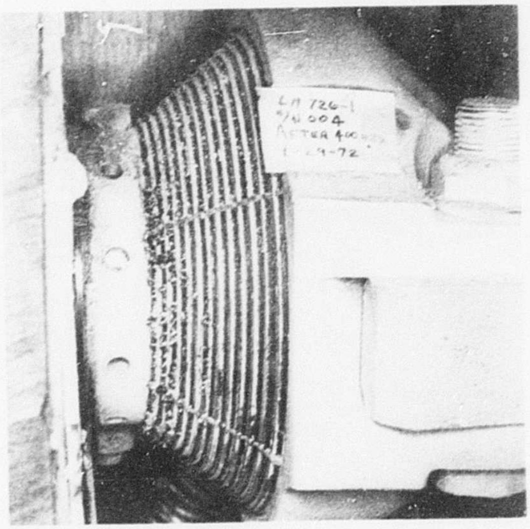


Figure 60. Test Sample 3
(S/N 004) in Dust
Chamber at 400
Hours.

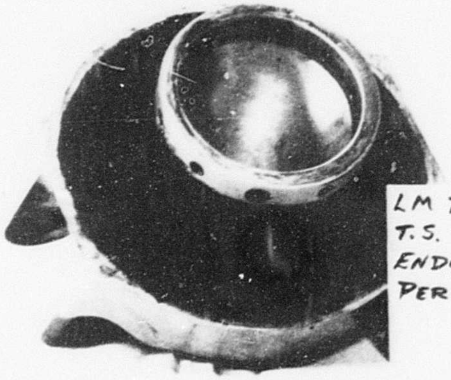


Figure 61. Test Sample 3 After Failure
at 800 Hours.

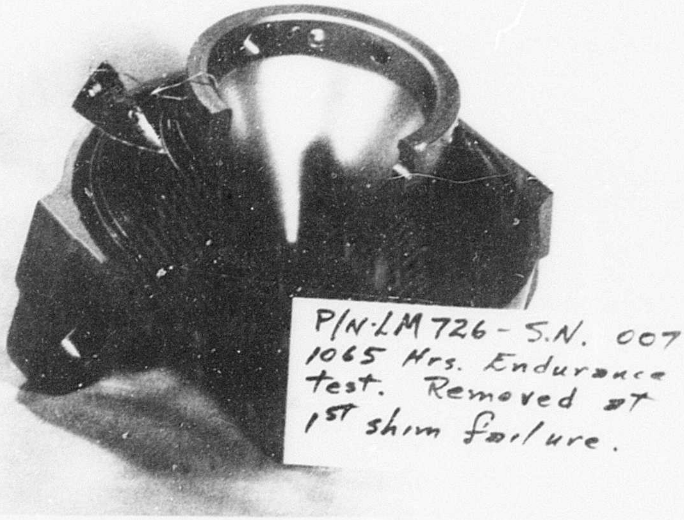


Figure 62. Sectioned View of Test Sample 6
(S/N 007) After Failure at
1065 Hours.

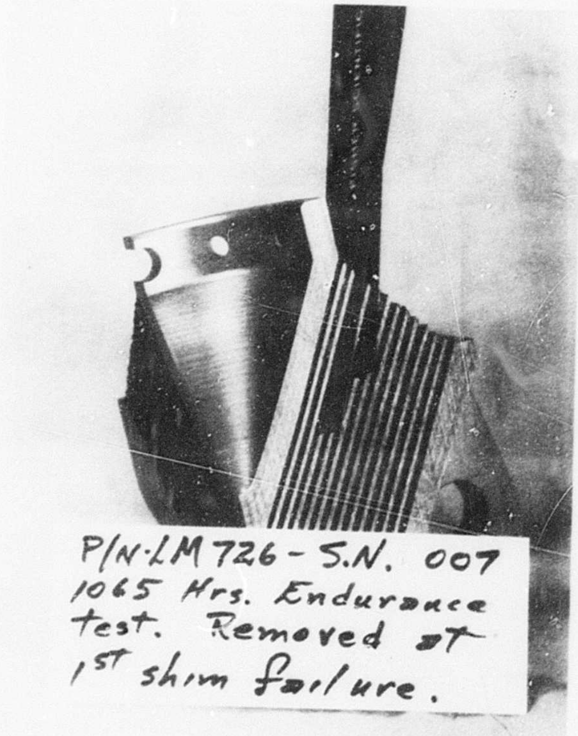


Figure 63. Test Sample 6 Showing Depth of Elastomer Loss.

CONCLUSIONS

PRE-ENDURANCE TESTING

The spring rate characteristics of the LM-726-1 were found to be acceptable for use in the intended application. Adequate controls on the elastomer resulted in a small variation in spring rate values within the sample lot tested. Consistent performance can be expected from production bearings using current fabrication techniques.

The axial repeated load test, experimental stress analysis, and ultimate load test established the strength of both the metal components and the flexing element. The test samples were determined to be suitable for continued testing. The new outer housing incorporated in the test bearings resulted in a better distribution of the centrifugal force load due to its increased beamwise stiffness. The effect of housing ovalling on the bearings' fatigue life was felt to be minimal with the redesigned housing as compared to the original housing as reported in USAAVLABS Technical Report 71-16.*

ENVIRONMENTAL ENDURANCE TESTING

The nature of the test procedure prevented a detailed examination of the effect of each environmental condition. The limitations in this type of environmental testing were fully realized and should be considered in evaluation of the bearings' performance. Among the limitations were:

> The inability to isolate the effect of any single environment because of the effects of the preceding environment.
>
> The inability to closely examine the appearance of the sample during each environment due to test machine design and environmental enclosures.

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*Fagan, C. H., FLIGHT EVALUATION OF ELASTOMERIC BEARINGS IN AN AH-1 HELICOPTER MAIN ROTOR, USAAVLABS Technical Report 71-16, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, March 1971, AD 725595.

Placement of periodic tests only at 200-hour intervals due to cost considerations precluding the measurement of performance changes due to several of the environments.

However, the combined effects of the environments imposed on two of the sample pairs did not alter their performance in comparison to the pair operating at room temperature throughout the test.

Exposure to high and low temperature did not result in a rapid increase in the rate of deterioration of the samples. Sand and dust exposure did not alter the bearing performance to any measurable degree. The simulated spillage of fluids on the bearing did not result in a failure of the bearings from attack on the elastomer or the bond. The bearings were unaffected by fungus exposure and were not measurably affected by humidity, salt fog, or ozone.

All of the six original samples were tested to failure. However, none of the bearings failed due to the failure criterion of a 40% decrease in the torsional spring rate. This did not cause concern because the selection of a 40% decrease as the criterion was rather arbitrary. Failure occurred due to shim failure, elastomer failure at a large pitch input, excessive heat buildup, and a large decrease in axial spring rate. All failures were a direct result of a loss of elastomer through abrasion.

All samples failed in a similar manner and at approximately the same rate. Elastomer abrasion began in the innermost sections where the maximum compression stress due to the radial load occurred. This area was directly in line with the radial load opposite the outer housing attachment lugs. Initial abrasion on all samples occurred at the 120- to 150-hour level, and continued throughout the test. As the test progressed, the abrasion spread to the entire circumference and outward to all sections.

The depth of abrasion was not significant until approximately 400 to 500 hours, when it had progressed to a depth of .20 to .70 inch. This loss of elastomer resulted in the failure of test sample 3 during the manual conditions at 800 hours. Shim failures and excessive heat buildup which resulted in failure of the remaining samples were caused by metal-on-metal rubbing due to elastomer loss.

Examination of Figures 43, 44, and 45 reveals a consistent trend in the performance of the test samples. The torsional spring rate of the samples, shown in Figure 43, decreased gradually until 1,000 hours and decreased sharply. The axial spring rate, shown in Figure 44, decreased gradually from 200 to 800 hours after a rather large decrease from zero to 200 hours. This initial decrease includes the bulk of the permanent set due to internal restructuring of the elastomer. The gradual decrease up to 800 hours is a result of elastomer loss from abrasion. The axial spring rate again decreased sharply at 800 hours and continued downward to failure. Figure 45, the permanent set envelope, illustrates a similar trend. The amount of set begins to level off in the 400- to 800-hour region. At 800 hours, the amount of set begins to increase at a more rapid rate.

The change in the above three parameters which occurred in the 800- to 1000-hour range may have been an indication of failure. Additional testing should include an investigation of these parameters to further define this apparent trend.

Radial load deflection testing was not of sufficient accuracy to be useful in monitoring bearing performance. The magnitude of the bearings' radial spring rate would require a sophisticated test fixture for accurate measurements. The radial spring rate of the bearing is an important consideration in evaluation of the helicopter rotor performance. If accurate radial load deflection data is considered essential, a separate fixture is recommended.

RECOMMENDATIONS

DESIGN CONSIDERATIONS

The primary factor in the initiation of failure of the LM-726-1 was the radial loading. It is recommended that future applications of the conical bearing include a reduction of the radial stress in the elastomer from the level used in the LM-726-1. This can be accomplished either through increased bearing size or through increased bearing spacing in the rotor installation. In addition, the geometry of the flexing element can be altered to provide better shim support for the radial load by improving the load path from the inner to outer housing. The amount of elastomer within the flexing element can be increased, within the limits of the rotor installation envelope, to provide an improved shear fatigue life. All of the changes are recommended for incorporation in an improved production version of the LM-726 type bearing.

INSPECTION AND REPLACEMENT CRITERIA

Laboratory testing can provide guidelines for the establishment of in-service inspection and replacement criteria. Actual flight evaluation will be required to provide additional criteria which can be expected to change with increased experience. Laboratory testing is particularly helpful in establishing the mode of failure, but past experience has proven it to be conservative when estimating life. Elastomeric bearings that have been flight tested have shown a considerable improvement in life compared to laboratory tests. There are several possible reasons for this.

A test block is established during which each test condition is imposed on the test bearing for a given percentage of time. The test block is repeated as many times as required to complete the total test duration. It is desirable to have a test block duration equal to a typical helicopter flight in order to closely duplicate service conditions. In some instances, cost considerations dictate a longer test block. The test block for the LM-726-1 was 40 hours. As a result, the amount of heat buildup during severe inputs exceeded that which would occur in service because of the difference in duration. The probable result of this additional heat buildup is a decrease in life, but of an unknown amount.

The amount of airflow across the bearings in service will greatly exceed that occurring in the laboratory. Fans added to the LM-726-1 test machine provide some cooling airflow, but of a lesser degree than expected in service. The bearings can thus be expected to run cooler in service with some improvement in life.

Based on the environmental endurance test of the LM-726-1, the following inspection guidelines can be established:

--- Bearings should be visually inspected at periodic intervals, perhaps before each flight, although flight experience may dictate less frequent inspections.

--- The initial deterioration will most likely occur in the quadrants directly in line with the radial loading (blade chordwise) and in the inner sections. This area should receive a particularly close inspection.

--- Exposed surfaces of the shims should be inspected visually for cracks, although cracks will most likely occur much later in the life cycle. A cracked shim should be considered a sufficient reason for bearing replacement.

--- The initial deterioration will most likely be an abrasion of the elastomer with the appearance similar to eraser particles. The airflow in the rotor head may prevent the buildup of these particles, necessitating a close examination of the elastomer surface to detect the deterioration.

--- Abrasion will continue in the initial location and gradually spread to other sections of the bearing. It will likely continue until elastomer loss reaches a measurable depth.

--- Additional test experience with the LM-726 type bearing will allow correlation of fatigue life with depth of elastomer loss. The elastomer loss results in a decrease in the bearing spring rate which will affect performance. A correlation between elastomer loss (measured depth) and spring rate may be

established which would be useful in monitoring bearing performance. Present information is not sufficient to establish an allowable depth of elastomer loss.

--- Measurement of bearing spring rates appears to be a useful means of monitoring the fatigue life of a bearing. However, such measurements would be difficult to accomplish without removal of the bearing from the aircraft. The failure criterion of a 40% decrease in torsional spring rate was not realistic. A decrease of approximately 20% appears to be a more realistic criterion in terms of bearing appearance and condition at such a level.

--- The axial deflection of the bearing when loaded to the normal centrifugal force increased as failure progressed. Upon establishment of allowable deflection levels, a sensor could be incorporated in the rotor to measure the outward blade travel due to bearing deterioration. The sensor could signal the inspector when the allowable axial deflection was exceeded.

APPENDIX

TEST PLAN FOR LM-726-1 RELIABILITY TESTING

I. INTRODUCTION AND OBJECTIVES

Reliability testing of an elastomeric product is designed to establish, by a series of tests including dynamic endurance under predicted service conditions, the adequacy of the design and manufacture of the parts.

The Test Program is presented first in general detail. Specific sections then describe the remaining details for the part.

Summary of Objectives:

A. Outline the details for establishing the reliability of the subject part.

B. Explain the basis for using the planned tests as proof of the airworthiness of the proposed part in the intended application.

C. Prepare inspection and replacement criteria.

II. APPLICABLE DOCUMENTS

The following documents form a part of this specification to the extent specified herein:

MIL-H-5606B	Hydraulic Fluid, Petroleum Base; Aircraft Missile and Ordnance.
MIL-C-45662A	Calibration System Requirements.
MIL-T-50301 (Mu)	Quality Control System Requirements for Technical Data.
MIL-STD-810B	Environmental Test Methods.
USAAVLABS Pamphlet 70-31	Standards for USAAVLABS Technical Reports.
ASTM-C-109	American Society for Testing & Materials.
ASTM-B-177	American Society for Testing & Materials.
LM-726	Lord Drawing Entitled "Elastomeric Bearing Bonded".

III. RESPONSIBILITY FOR TESTS

Lord Manufacturing Company will supply the necessary number of parts for the test. USAAVLABS or Bell Helicopter designated representatives may witness any and all portions of the testing.

IV. TEST PLAN OUTLINE

A. Pre-Endurance Tests

1. Thorough inspection of physical characteristics will be performed.

2. Static load-deflection test in rotation about X-X axis (refer to sketch on Page 19), compression along X-X axis, and radial along Y-Y axis (in line with clevis centerline) will be performed on Test Sample 1 through 15. Test Samples 7, 8, and 9 will also be load-deflection tested radially along the Z-Z axis (perpendicular to clevis centerline).

3. Dynamic load-deflection will be performed about the X-X axis and along the Y-Y axis at a typical amplitude condition and frequency. Dynamic spring rates will be obtained on Test Samples 1 through 6.

4. Three (3) bearings will be used in obtaining ultimate load data, axial (compression) fatigue data, instrumented stress data, and internal physical construction characteristics. (Test Samples 7, 8, and 9.)

B. Endurance Testing

1. Dynamic Endurance testing will be performed on six (6) bearings in pairs subjected to simulated in-service loads, motions, and environments.

2. Dynamic and static spring rate measurements, photographs, and mechanical inspection for each of the six test parts before endurance testing and at 200 hour intervals at a typical condition and in the modes in which dynamic endurance testing is scheduled.

C. Test Reports

Within 60 days of completion of the contract, a draft of the final test report shall be submitted by Lord Manufacturing Company containing results of the test series and a description of achieved reliability. Format shall be in accordance with USAAVLABS Pamphlet 70-31.

A reproducible final report shall be submitted together with the annotated draft within 30 days after receipt of the Government's annotated draft report. Content of the Final Report will be in accordance with DI-S-1800 as amended.

This report will include:

1. A summary of all test conditions and procedures.

2. All results and data obtained from the endurance and environmental tests.

3. Photographic Coverage

    a) Black and white photographs exposed in 4 x 5 size will be taken throughout the testing for inclusion in the final report.

    b) Provide periodic photographs of the test parts at the 200 hour intervals, or sooner, if failure is evident.

    c) Provide stills of test equipment, test set-ups, and test parts both prior to, during, and after completion of tests.

4. A record of all failures, modes of failure, and rates of failure, whether considered valid or invalid.

5. Recommended inspection and replacement criteria based on test results.

6. A summary of spring rates and changes throughout the tests at intervals specified for individual bearings.

V. GENERAL DETAILS OF TEST PHASES

A. Pre-Endurance Testing

1. Mechanical Inspection

Dimensional inspection will be performed on every part to insure that the requirements of Lord drawings are maintained. Serialization of the parts will be done at this time.

2. Static Spring Rate Check

As a further means of establishing the performance characteristics of each bearing at the start of endurance testing (and also to identify part-to-part variations, if any), every test part will be subjected to two standard static load-deflection tests before dynamic testing begins (see IV.A.2., Page 4). These tests will be as established in the test schedule for the specific parts. As convenient, these tests will be performed either in the dynamic test machines in the directions for which load and motion read-out are provided, or in Universal Test Machines.

3. Dynamic Spring Rate Measurement

Dynamic stiffness data will be obtained either during initial cycling on the endurance test machines or on separate set-ups with substitute fixturing. The dynamic spring rates for each test part will be determined at a typical amplitude condition and frequency for rotation about X-X axis and radial along Y-Y axis. The values will be calculated from peak-to-peak load divided by total amplitude. Dynamic-to-static ratio is considered equal for both modes except that metal part flexing may slightly reduce the ratio in specific directions.

B. Endurance Testing

1. General Endurance Test Discussion

Six specimens of the final configuration will be subjected to a maximum of 1000 hours of dynamic

testing. The endurance testing will be conducted in electro-hydraulic test machines.

The radial loading and torsional motions shall be in phase with each other. Each pair of bearings will be tested to the spectrum shown in Table I, unless interrupted by failure, for 200 hours at room temperature conditions until all have completed this time, then the pairs will complete the additional testing to 1000 hours maximum, or to failure. A recycling time block for the various load/motion conditions will be established on the basis of equipment limitations and convenience, but will not exceed 40 hours.

Log books will be kept for each test to record all part and serial numbers, adjustments and results. Photographs, inspection, and testing for static and dynamic spring rates are scheduled at 200 hour intervals to show any developing failure in stages.

2. The endurance loads and motions will be hydraulically actuated and electronically controlled. The torsional motion actuator is displacement controlled, while the radial load actuator will be pressure controlled. The test spectrum (frequency of motion and loads vs. percentage operating time) will be controlled by a signal generator in conjunction with a variable phase control unit, a load and displacement controller, and an amplitude and time base programmer.

3. The test machine and/or fixturing will be instrumented to allow measurement and recording of the torsional motion and radial loading. Accuracy of all test conditions shall be held to within ± 3% of the specified load, motion, and frequency, and shall be traceable to the Bureau of Standards.

4. A description of the instrumentation shall be provided. The calibration procedures shall be in accordance with MIL-C-456624, "Calibration System Requirements".

5. Failure Criteria

Failure will be defined primarily as a 20% increase or a 40% decrease in room temperature static spring rate about the torsional axes, but testing of any part may be discontinued earlier if other failure modes and/or if Lord Engineering judgement suggests such course of action.

6. Test Recycling

Provision for recycling of the reliability test has not been included in the quote. If recycling becomes necessary due to part failure or malfunction, Lord Manufacturing Company will supply the required parts.

7. Status Reports

Any significant occurrence during the endurance testing will be discussed in a monthly report of progress by Lord Manufacturing Company. Problems which could delay the Test Program will be reported immediately by telephone or telegraph.

VI. PART NUMBER LM-726-1 TEST PLAN (Refer to drawing LM-726-1 in Appendix)

A. Pre-Endurance Tests of Qualification Test Samples

1. Inspection of Test Samples

The test parts will receive a special inspection supplementing normal quality control to identify specific values of physical and performance characteristics. This will assure that the design objectives were achieved and will permit later inspection after testing to detect small changes in characteristics. At this point, the part will be permanently serialized for identification purposes throughout the test program. The parts shall be photographed in an unstressed condition (no external loads). Inspection will include:

For all test parts, accurate dimension measurement and tabulation of dimensions affected by yield, set, or drift, including as applicable: (Ref: Drawing LM-726, Rev. H)

a) Parallelism or perpendicularity of external metal parts.
   3.90 in. - 2 places (along axis of each pair of .7505/.7495 holes). 5.501/5.500, 2.755/2.750.

b) Concentricity of external metal parts.
   3.400 in. diameter - 2 places at 90° to each other. 6.20 in. diameter 6.15 in.

c) Height or thickness (of LM-726-1). This is covered by 3.90 in. dimension.

d) Torsional set (about X-X axis). Check angular position of .25 inch diameter holes on inner member with 5.501/5.500 dimension on outer member.

e) Flatness of LM-726-1 attachment surfaces. This is covered by 3.90 in. dimension.

f) .7505/.7495 diameter -- 4 holes, 1.393/1.391 - 2 places.

g) Check for fretting of attaching surfaces and visually check for cracks in metal parts and shims.

2. <u>Static Spring Rates - All Test Samples</u>

The static spring rate around the X-X (torsional) and along the Y-Y axis (radial) will be measured. Rotation around the X-X axis will be recorded up to 20°. The radial (along Y-Y axis) stiffness shall be measured up to 12,000 pounds. The axial (compression) stiffness shall be measured up to 56,000 pounds (along X-X axis). The spring rate measurements will be identified with the appropriate serial number of the

test part. The speed of loading and unloading, unless otherwise specified, will be 30° per minute torsional, .02 inches per minute radial, and .125 inches per minute axial (compression). Test Samples 7, 8, and 9 will also be tested along the Z-Z axis (radial) to a 12,000 pound load.

The axial load of 56,000 pounds will be imposed on the bearings during the radial and torsional spring rate tests. The bearings shall be tested in pairs for the radial and torsional spring rate tests.

3. <u>Ultimate and Axial Load Testing</u>

Three (3) bearings will be used in obtaining ultimate load data, axial fatigue data, instrumented stress data, and internal physical characteristics.

<u>Test Parts 7 and 8</u>

Test Samples 7 and 8 will have been photographed and dimensionally inspected prior to spring rate and axial fatigue testing. Axial load-deflection data will be obtained on both samples loaded to 56,000 pounds individually. Torsional load-deflection data on the individual parts with no axial load will be obtained as well as torsional data on the pair when subjected to 56,000 pounds of axial load. Radial load-deflection data will be obtained for loading parallel to the clevis centerline and perpendicular to the centerline, while the pair are subjected to a 56,000 pound axial load. Upon completion of load-deflection testing, test parts 7 and 8 as a pair will be subjected to axial (compression) fatigue testing. The parts will be loaded 0 to 84,000 pounds to 0 for a total of 5000 cycles. At the completion of this test, spring rate checks and test part inspection will be performed and photographs taken. Then one of these parts will be sectioned to show internal physical construction characteristics.

Test Part 9

After placement of strain gages, the location and number of which may be determined by brittle coating, Test Part 9 will undergo spring rate checks and test part inspection. Photographs will be taken. Test Sample 9 will then be installed in the test fixture with Test Sample 7 (prior to testing of Test Sample 7) and load-deflection tested while monitoring the strain gages. Axial, torsional, and radial testing will be as outlined for Test Samples 7 and 8 above. The part will then be loaded in an axial direction to 200,000 pounds and the load-deflection characteristics recorded. At least one strain gage will be monitored as much as feasible during the 200,000 pound load test. At the completion of this test, spring rate checks will be performed as possible depending on the condition of the part. Test part inspection will be performed and appropriate photographs taken.

B. Endurance Tests

1. General Comments

a) The operating endurance test spectrum is described in Table I. Six bearings shall be subjected to 200 hours of this spectrum initially at room temperature conditions. Spring rates shall be taken initially and after 200 hours as specified.

b) The test environments which will be used are as described in MIL-STD-810B, dated 15 June 1967. The specific methods are as described in Methods 501, Procedure II; 502, Procedure I; 507, Procedure II; 508, 509, and 510, Procedure I, with modifications as specified. The distribution of environments is as shown in Table II.

c) High Temperature, Method 501, Paragraph 3.2, Procedure II, to be performed in accordance with Step 8 modified to read "Operate the test parts for a period of 40 hours at an ambient temperature of 130°F.".

d) Low Temperature, Method 502, Paragraph 3.1, Procedure I, to be performed in accordance with Step 2 modified to read, "Storage temperature will be -65°F. ± 5°", and Step 4 modified to read, "Lowest operating temperature will be -65°F. ± 5° for a period of 160 hours".

e) Fungus, Method 508, with the following change: "At the end of the incubation period, the test item shall be subjected to the 200 hour room temperature break-in test scheduled for this set of bearings."

f) Dust, Method 510, Paragraph 3.1, Procedure I, to be performed in accordance with Step 1, with the first sentence modified to reflect a relative humidity of less than 40 per cent and the last sentence changed to read, "With the test item operating, maintain these conditions for 200 hours" and Step 3 with the last sentence modified to read, "With the test item operating, maintain these conditions for 200 hours."

g) Salt Fog, performed in accordance with Method 509, with the following modifications: In 3.1.6, Performance of Test, change sentence two to read, "The test item shall be operated for a period of 48 hours in a salt fog atmosphere in accordance with the salt solution specified in paragraph 2.4 at a rate of 1 milliliter per hour for each 80 cm^2 of horizontal area." Change sentence six to read, "At the end of the drying period, the test item shall be again operated for 48 hours."

h) Humidity, Method 507, Paragraph 3.2, Procedure II, to be performed in accordance with Step 6 with the following modifications: Omit first and second sentences and substitute, "Operate the test item for five continuous 40-hour cycles in accordance with Figure 507-2."

i) Using Sections 3 and 4 of MIL-STD-810B, 15 June 1967, as test procedure and sequence guides, the bearings shall be operated for the given times and exposure conditions to the following potential reactants:

	Reactant	Test Duration Hrs.	Exposure Conditions
(1)	Ozone	16	Tested in a concentration of 25 $\pm$ 5 PPHM of ozone in air by volume.
(2)	JP-4, Jet Fuel	66	Test parts thoroughly wetted with reactant prior to start of test.
(3)	Varsol	67	Test parts thoroughly wetted with reactant prior to start of test.
(4)	Methyl Ethyl Ketone	67	Test parts thoroughly wetted with reactant prior to start of test.
(5)	Hydraulic Fluid (MIL-H-5606)	160	Test parts sprayed with mist of reactant during the first five (5) hours of test and again for five (5) hours after the completion of 80 hours of the test spectrum. A quantity of .6 quarts shall be sprayed on each part within each of the two (2) five-hour periods.

Note: The fluids called out in VI.B.1.i.,1, 2, 3, and 4 will be wiped dry after application. The bearing will encounter these fluids only due to accidental spillage. Under no circumstances shall any of the above reactants be removed from the bearings other than by wiping with a clean dry rag.

j) Room temperature conditions shall be the standard ambient conditions as outlined under 3.1, Test Conditions, in MIL-STD-810B, 15 June 1967.

k) Low Temperature -- To supplement Method 502, Low Temperature, as outlined in VI.B.1.d., the following procedure will be utilized for low temperature start-up. The bearings will be cold soaked until the inner member surface of the bearing reaches -65°F. ± 5° at which time testing will be started. Prior to beginning, the outer member must be within +15°F. or -5°F. of the desired -65°F. A low temperature, -65°F. start-up procedure will be utilized. The low temperature start-up will involve one sinusoidal cycle rotation about the X-X axis either with 12,000 in.-lbs. torque or 3° (at 3 CPM) whichever is limiting, and then returning to the no-load position. Next, ten sinusoidal cycles to ± 6000 in.-lbs. torque or ± 1-1/2°, whichever is limiting, will be applied at 10 CPM. The frequency of this condition will then be increased to the standard 324 CPM and torque input gradually reduced to maintain the 3° amplitude limit. When bearing warm-up due to hysteresis has reduced the torque to approximately ± 2000 in.-lbs., the normal test spectrum will be imposed. The elapsed time for this warm-up period will be recorded.

l) High Temperature -- To supplement Method 501, High Temperature, as outlined in VI.B.1.c., the following guidelines will be used. The test spectrum conditions in Table I will not commence until the bearing inner member surface is within ± 5° of the desired temperature. Prior to beginning, the outer member must be within +5°F. or -15°F. of the desired ambient temperature. Design of the heat source should be such that "overshooting" the desired bearing surface temperature by more than 10°F. momentarily is not permitted. As soon as testing begins, maintain the desired ambient temperature within ± 5°F. To avoid local hot spots within the test chamber, air is to be circulated. These guidelines will also apply to the temperatures imposed during testing under Method 507, Humidity (VI.B.1.h.) and Method 510, Dust (VI.B.1.f.).

2. <u>Test Sequence</u>

a) The test sequence and time intervals for the LM-726-1 bearings will be as follows.

b) Test samples 1 and 2. After the initial 200 hours of testing to the spectrum shown in Table I at room temperature conditions, an additional 800 hours of testing under this test spectrum at room temperature conditions will be performed.

c) Test samples 3 and 4. After the initial 200 hours of testing to the spectrum shown in Table I at room temperature conditions, additional testing under this spectrum will be performed as follows: 400 hours as described under Method 510, <u>Dust</u>, as outlined in VI.B.1.f. This will be followed by an additional 200 hours of exposure to JP-4, Varsol, and Methyl Ethyl Ketone as outlined in VI.B.1.i. Following this, 160 hours of exposure to MIL-H-5606 Hydraulic Fluid will occur as outlined in VI.B.1.i. This 200 hour block will be completed with 40 hours of room temperature testing. The balance (200 hours) of the 1000 hour test will be performed at Room Temperature.

d) Test samples 5 and 6. After Method 508, <u>Fungus</u>, as outlined in VI.B.1.e. and the initial 200 hours of testing to the spectrum shown in Table I at room temperature conditions, additional testing under this spectrum will be performed as follows: 40 hours as described under Method 501, <u>High Temperature</u>, as outlined in VI.B.1.c.; 160 hours as described under Method 502, <u>Low Temperature</u>, as outlined in VI.B.1.d.; 200 hours as described under Method 507, <u>Humidity</u>, as outlined in VI.B.1.h.; 96 hours (48 at room temperature conditions) as described under Method 509, <u>Salt Fog</u>, as outlined in VI.B.1.g.; 16 hours under <u>Ozone</u> requirements as outlined in VI.B.1.i. (1). The balance (288 hours) of the 1000 hour test will be performed at room temperature conditions.

3. Periodic Part Inspection

a) Photos

Photographs shall be taken at the completion of every 200 hours maximum of endurance testing or as specified. If failure is anticipated, photos will be made at intervals of 48 hours minimum. The photos will be taken as installed in the test machine where the machine design permits, otherwise in an unstressed condition out of the machine.

b) Spring Rates

The static spring rate around the X-X (torsional) and along the Y-Y axis (radial) will be measured up to 20° and 12,000 pounds, respectively, initially. The static spring rates will be performed as defined in paragraph VI.A.2. The dynamic torsional stiffness (around X-X axis) will be measured initially at 0° ± 12° at 324 CPM after one minute of cycling.

Dynamic radial stiffness (along Y-Y axis) will be measured initially at 9000 pounds ± 8000 pounds at 324 CPM after one minute of cycling.

The axial load of 56,000 pounds will be maintained during all radial and torsional spring rate tests.

The axial spring rate will be measured initially at 0 to 56,000 pounds to 0 at 5 CPM after one minute of cycling.

The spring rates will be measured every 200 hours unless otherwise specified.

c) Mechanical Inspection

Dimensional inspection will be performed on every part to insure that the requirements of Lord drawings are maintained. Serialization of the parts will be done at this time. The parts shall be replaced in the same position each time they are removed from the test fixtures for inspection.

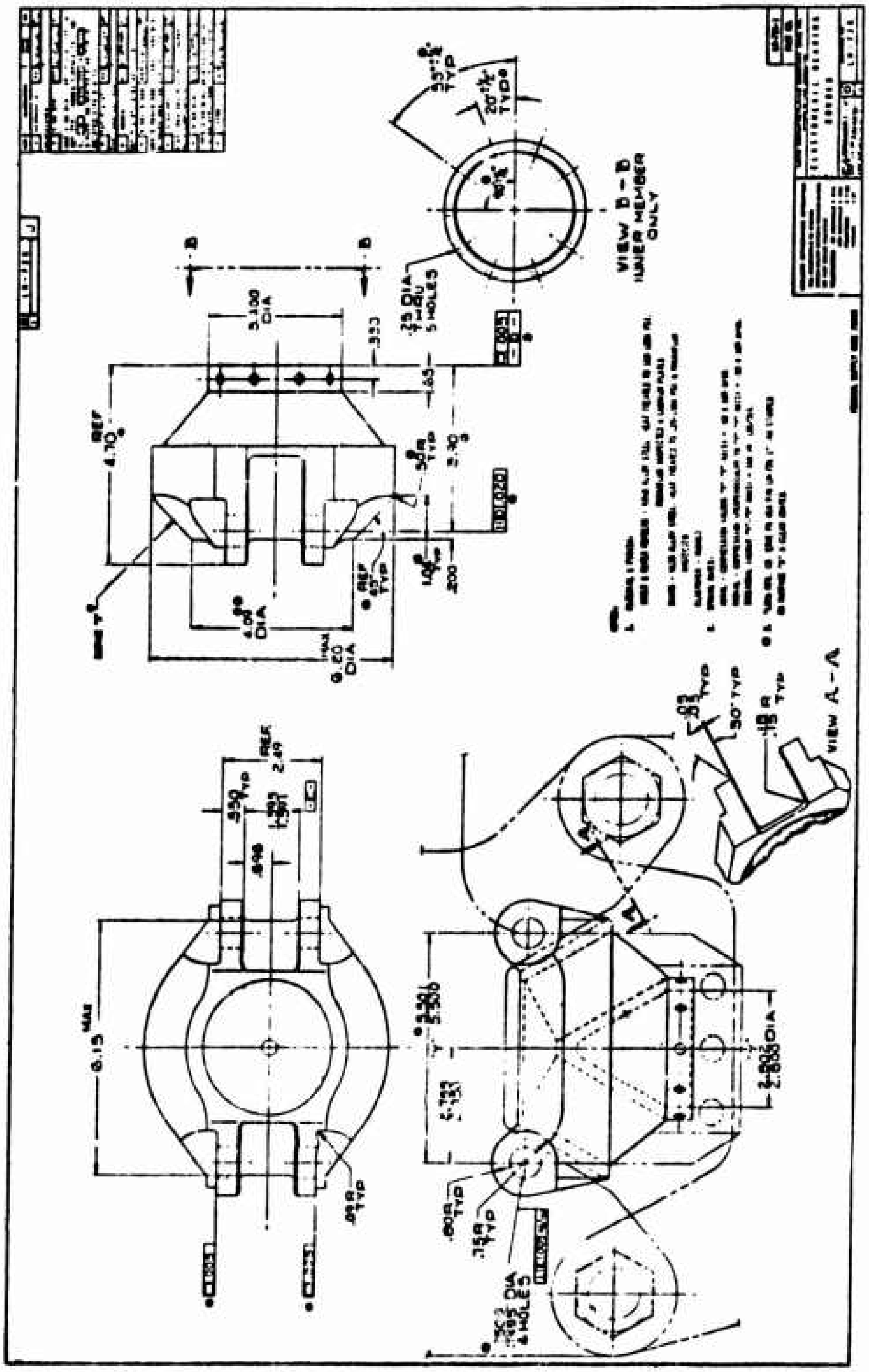

Figure 64. LM-726-1 Drawing, Revision J.